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Use of Organic Solvents in Textile Sizing and Desizing

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Textile Processes	Stationary Sources	13H
Textiles	Slashing	11E
Sizing	Desizing	
Organic Solvents	Aqueous Sizing	11K 06C
Industrial Water		
Waste Water		
Wastewater Treatment		
Biochemical Oxygen Demand		
Yarns		
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USE OF ORGANIC SOLVENTS IN TEXTILE SIZING AND DESIZING

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FOREWORD

Most of the work done in this study involved the use of tetrachloroethylene (perchloroethylene) as the solvent for textile slashing and desizing operations. On March 25, 1977, the National Cancer Institute reported that perchloroethylene is a carcinogenic material, causing liver cancers in mice. The report covering these findings will be available from the National Cancer Institute about July 1, 1977.

This report has been reviewed by the Industrial Environmental Research Laboratory, U. S. Environmental Protection Agency, and approved for publication. Such approval does not constitute endorsement or recommendation for use of perchloroethylene in textile processes.

John K. Burchard, Director, IERL/RTP

ABSTRACT

Results of a study of slashing and desizing in organic solvents are reported. Properties of materials applicable as warp sizes in systems utilizing organic solvents were satisfactory for utilization as warp sizes. Evaluations wherein solvent sized yarns were successfully woven into fabric using conventional weaving techniques are described. Properties of fabrics made from solvent sized yarns are compared to properties of fabrics made from aqueous sized yarns. No deterioration in quality of the fabric occurred when organic solvents replaced water in slashing and desizing.

The energy consumption of solvent slashing and desizing systems is compared to energy consumption in conventional aqueous systems. Total energy consumption of solvent slashing and solvent desizing systems currently available is essentially equivalent to that in conventional aqueous systems.

Economic aspects of solvent slashing and desizing are discussed. Cost of solvent and aqueous slashing and desizing were nearly equivalent when the cost calculation included 1983 wastewater treatment costs. The majority of the materials cost in solvent slashing and desizing is the cost of solvent lost in the process. Elimination or reduction of the 7.2% loss calculated in this study could result in a distinct cost advantage for the solvent system.

Solvent slashing and desizing would eliminate virtually all of the BOD load typically resulting from sizing and desizing. The retention of perchloroethylene in polyester fiber can be maintained at a very low level provided the temperature of exposure of the fiber to the solvent is below the glass transition temperature of the fiber. Perchloroethylene is rapidly and easily removed from cotton fibers in the drying process. Solvent loss to the atmosphere from currently available solvent slashing and desizing machinery is reported to total about 0.0723 pounds per pound of fabric. Reductions in this level of loss can probably be expected if the machinery and techniques are refined.

This report was submitted in fulfillment of EPA Grant No. R803665 by the Auburn University Textile Engineering Department under the partial sponsorship of the U.S. Environmental Protection Agency. The work was performed in cooperation with the Alabama Textile Education Foundation through the Auburn University Engineering Experiment Station. This report covers the period from May 1, 1975 to December 31, 1976 and work was completed as of January 15, 1977.

	Page
Foreword	iii
Abstract	iv
Figures	vi
Tables	vii
Abbreviations and Symbols	ix
Acknowledgement	x
1. Introduction	1
2. Conclusions	4
3. Recommendations	6
4. Properties of Solvent Sizing Materials	7
5. Properties of Solvent Sized Yarns	12
6. Weaving of Solvent Sized Yarns	24
7. Fabrics Containing Solvent Sized Yarns	27
8. Solvent Removal During Drying	32
9. Effects of Solvent Sizing and Desizing on the Environment	44
10. Energy Consumption of Aqueous and Solvent Sizing and Desizing Systems	54
11. Economic Evaluation of Solvent Sizing and Desizing	60
Reports and Publications	65
Appendices	66

FIGURES

Number		Page
1	Schematic Diagram of a Solvent Slashing and Solvent Desizing Process	3
2	Schematic Diagram of Single Yarn Size Applicator	13
3	Schematic Diagram of Laboratory Slasher	14
4	Photograph of the Laboratory Slasher	15
5	Scanning Electron Micrograph of 100% cotton yarns unsized (first 3 on left) and containing about 15% by weight of ethyl cellulose (last 4 on right). Magnification 20X.	20
6	Scanning Electron Micrograph of 100% Cotton Yarns containing about 10% by weight of Polyvinyl Alcohol. Magnification 100X.	21
7	Scanning Electron Micrograph of 100% Cotton Yarns containing about 12% by weight of Hydroxypropyl Cellulose. Magnification 100X	22
8	Weave, draw and can drafts used for weavability trials.	25
9	Effect of Bath Temperature on the Retention of Perchloroethylene in Polyester Fabrics.	34
10	Effect of Perchloroethylene Bath Temperatures on the Retention of Perc in Polyester Fabrics	35
11	Weight Percentage of Perchloroethylene Retained by Polyester Fabric After Drying for 2.5 Minutes at Various Temperatures.	39
12	Weight Percentage of Perchloroethylene Retained by Polyester Fabric After Drying for 5.0 Minutes at Various Temperatures.	40
13	Solvent Sizing Flow Diagram	58
14	Solvent Desizing Flow Diagram.	59

TABLES

Number		Page
1	Properties of Ethyl Cellulose, Hydroxypropyl Cellulose, Polyvinyl Alcohol and Carboxymethyl Cellulose	10
2	Breaking Strength of 100% Cotton and 50/50 Polyester/Cotton Blend Yarns Sized with Polyvinyl Alcohol from Water, Ethyl Cellulose from Perchloroethylene or Hydroxypropyl Cellulose from Water.	17
3	Elongation at the Break of 100% Cotton and 50/50 Polyester/Cotton Blend Yarns Sized with Polyvinyl Alcohol from Water, Ethyl Cellulose from Perchloroethylene or Hydroxypropyl Cellulose from Water	18
4	Abrasion Resistance of 100% Cotton and 50/50 Polyester/Cotton Blend Yarns Sized with Polyvinyl Alcohol from Water, Ethyl Cellulose from Perchloroethylene or Hydroxypropyl Cellulose from Water.	23
5	End Breakage Rates for Warps Sized with Various Sizing Materials	26
6	One-Inch Ravelled Strip Strength and Elongation for Fabrics Sized with Various Sizing Materials.	28
7	Tear Strength for Fabrics Sized with Various Sizing Materials as Determined on the Elmendorf Tear Tester	29
8	Abrasion Resistance of Fabric Samples Sized with Various Sizing Materials	30
9	Retention of Perchloroethylene by Polyester Fabric After Immersion for 15 Minutes at Various Bath Temperatures and Ambient Air Drying	36
10	Rates of Removal of Perchloroethylene from Polyester Fabric at Various Drying Temperatures.	38
11	Retention of Perchloroethylene in Polyester Fabric After Drying the Pure Saturated Fabric for 2.5 and 5.0 Minutes at Various Temperatures	38

Number		Page
12	Rates of Removal of Dichloromethane from Polyester Fabric	42
13	Retention of Dichloromethane in Polyester Fabric After Drying the Saturated Fabric for 2.5 and 5.0 Minutes at Various Temperatures	42
14	Energy Consumption, Exhaust Air Quality and Cost for Sizing Warp Yarn with Aqueous Systems in Typical Plants	45
15	Energy Consumption, Exhaust Air Quality and Cost for Desizing with Aqueous Systems in Typical Plants	46
16	Pollutional Load Contributed by Desizing Various Sizing Materials	48
17	Environmental Effects of Aqueous and Solvent Sizing (Slashing) Systems	49
18	Environmental Effects of Aqueous and Solvent Desizing Systems	52
19	Summary of Environmental Effects of Aqueous and Solvent Sizing and Desizing Systems	53
20	Energy Consumption of Aqueous and Solvent Sizing (Slashing) Systems	55
21	Energy Consumption of Aqueous and Solvent Desizing Systems	56
23	Summary of Energy Consumption of Aqueous and Solvent Sizing (Slashing) and Desizing Systems	56
23	Costs of Aqueous and Solvent Sizing (Slashing) Systems	61
24	Costs of Aqueous and Solvent Desizing Systems	62
25	Summary of Costs of Aqueous and Solvent Sizing (Slashing) and Desizing Systems	63

ABBREVIATIONS

BAT	=	Best Available Technology
BOD	=	Biochemical Oxygen Demand
BPT	=	Best Practicable Control Technology
CMC	=	carboxymethyl cellulose
cm	=	centimeter(s)
COD	=	Chemical Oxygen Demand
EC	=	ethyl cellulose
HPC	=	hydroxypropyl cellulose
in	=	inch(es)
mil	=	0.001 inch
min	=	minutes
oz	=	ounce(s)
PE	=	polyester
perc	=	perchloroethylene
psi	=	pounds per square inch
PVA	=	polyvinyl alcohol
sec	=	second(s)

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SECTION 1

INTRODUCTION

Warp sizes make a sizeable contribution to the waste load from a textile finishing plant. Published data indicates that 45% of the BOD load from a textile finishing plant usually results from warp sizes, and as much as 75% of the BOD load may result from this source. The BOD loading by warp sizes comes from three processes. Slashing, application of size to give the yarn the necessary characteristics for weaving, contributes some waste size material which must be discharged. Desizing and scouring, conversion of the size to water soluble products and removal of these materials from the woven fabric, also contributes greatly to the BOD load. Many figures on the BOD load resulting from desizing and scouring are available in the literature. However, these figures differ greatly depending on the source from which they are obtained and the type of process they represent. Therefore, the hypothetical situation described below is probably as typical as any published data.

If a fabric consisting of 60% warp is being processed and the warp yarn in the fabric contains 15% starch size, then 90 pounds* of starch will be removed from each 1000 pounds of fabric processed in the desizing and scouring. Since starch has a BOD of approximately 50%, 45 pounds of BOD per 1000 pounds of fabric will result. Also, 5% fats, waxes and oils having BOD of about 80% will be removed from the fabric. This will contribute an additional 4 pounds of BOD per 1000 pounds of fabric processed. If 10 gallons of water are used per pound of fabric in these processes, this 49 pounds of fabric will give a wastewater from these processes of 500 ppm of BOD.

While the greatest polluting characteristic of starch based warp sizes is the BOD load generated, the amounts of COD and suspended and dissolved solids are also large. This is especially true where sizes such as carboxymethyl cellulose (CMC) or polyvinyl alcohol (PVA) are substituted for starch sizes. Substitution of these materials lowers the BOD load from the process, but they must be dealt with from the standpoint of COD and suspended solids.

The logic for study of the application of size materials to warp yarns from organic solvents is in the potential for recovery and reuse of the solvent and size material. Solvent technology in textile processing has been the subject of much study in recent years. The solvents which have been deemed most appropriate for processing of textile materials are the chlorinated hydrocarbons. Dichloromethane, 1, 1, 1- trichloroethane, trichloro-

*English units are most commonly used and best understood in the textile industry. Factors for conversion to metric units are in Appendix I.

ethylene and tetrachloroethylene (perchloroethylene) have all been found applicable in certain processes. Of these, perchloroethylene (perc) has been most studied and used. Most of the work done in this study involved the use of perc, but in certain instances 1, 1, 1,- trichloroethane, dichloromethane and 1, 1,2- trichloro-1,2,2- trifluoroethane were used. The properties of these solvents are extensively documented.

Since cotton, polyester and blends of these two fibers comprise the largest group of textile fabrics, these fibers were used for this work.

The process which was the subject of the research proposal leading to this study is diagrammed schematically in Figure 1. The size material would be applied to the yarn in an enclosed size box probably at room temperature. The solvent would be removed from the yarn in an enclosed dryer and reclaimed by condensation. The size would be removed from the fabric using solvent. Insoluble impurities such as loose fiber would be removed by filtration. The size solution from desizing would be distilled to recover most of the solvent and to concentrate the solution back to the solids content required for sizing.

The results reported in the following sections pertain to properties of potential solvent warp sizes, weaving performance of yarns containing solvent sizes, and the environmental and economic impact of sizing/desizing systems using organic solvents.

Early in the project the idea evolved that size which could be desized using an organic solvent but which could be applied in slashing using conventional aqueous techniques would be more acceptable and more easily adaptable in the textile industry than a complete solvent slashing/solvent desizing system. Further, this aqueous slashing/solvent desizing would still accomplish the objective of reclamation of the size material for reuse. Therefore, an additional aspect of the work was to determine the potential as warp sizes of materials which are soluble in both water and organic solvents.

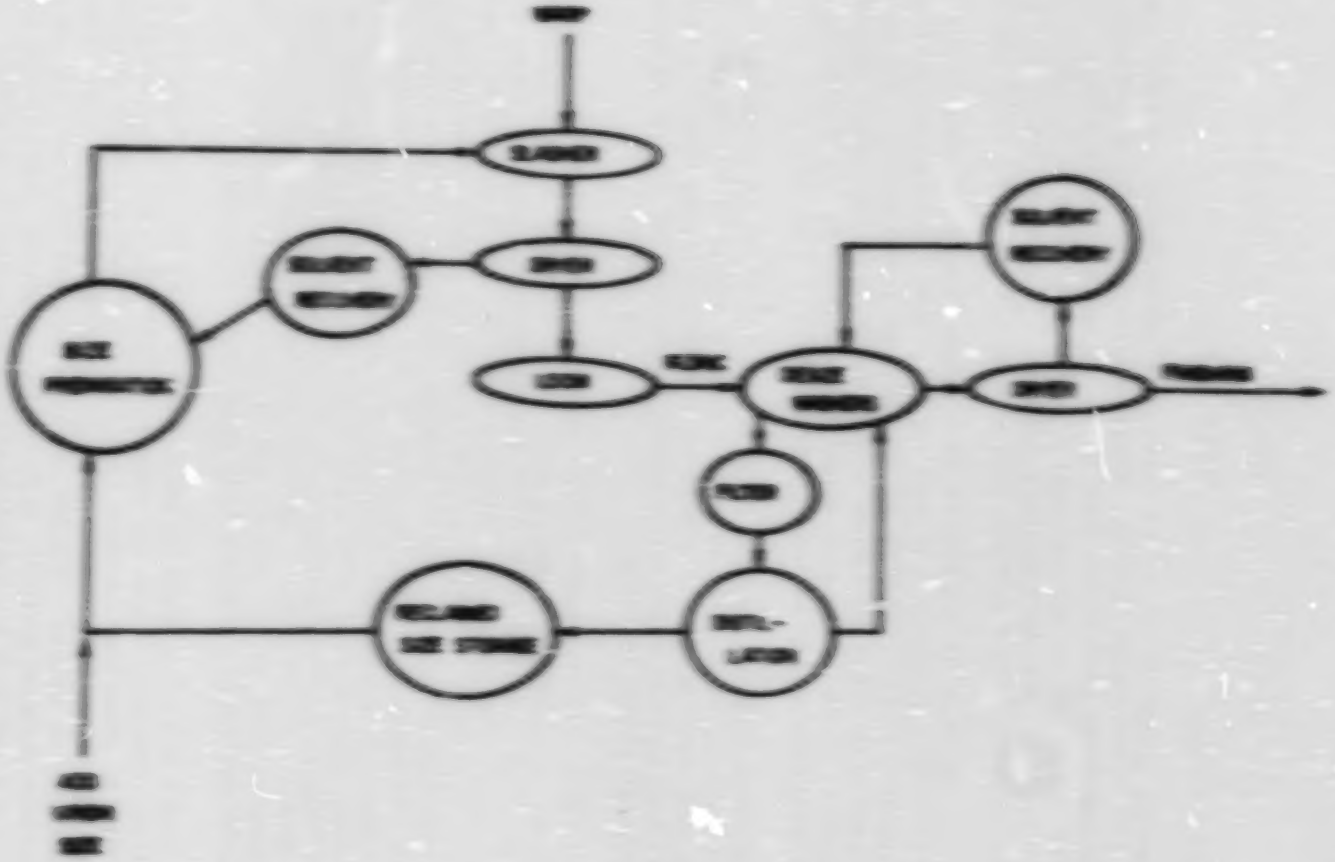


FIGURE 1. [illegible]

SECTION 3

CONCLUSIONS

Textile yarns may be sized using perchloroethylene or methylene chloride as the size application medium. Ethyl cellulose and hydroxypropyl cellulose are applicable as warp sizes from these solvents, respectively. These solvent warp sizes can be desized using organic solvents after which the solvent and size material can be partially recovered through a distillation process. The properties of the recovered size and solvent are adequate for recycle.

Since the cost of production of a woven fabric depends very closely on the efficiency with which the yarn can be woven into fabric, much work was done regarding the performance of the solvent sized yarns. The properties of yarns sized with ethyl cellulose and hydroxypropyl cellulose were essentially equivalent to those of aqueous sized yarns. Weaving tests indicated that the solvent sized yarns can be woven satisfactorily into fabric.

The properties of fabrics made from solvent sized yarns are equivalent to properties of fabrics from yarns sized by conventional aqueous techniques. Fabrics made from solvent sized yarns can be processed satisfactorily through conventional aqueous scouring, bleaching, dyeing and finishing processes subsequent to the desizing step.

Polyester fibers absorb perchloroethylene when the fibers are exposed to the solvent at elevated temperatures. Some of this solvent is released by the fiber only slowly even at high drying temperatures. Thus, perchloroethylene loss from polyester scouring systems, which has often been reported as 3% to 7% of fabric weight, probably results mainly from solvent carried out of the system in the fiber. However, polyester fibers absorb and retain little or no solvent if the exposure of the fiber to the solvent is at room temperature. Since solvent slashing and desizing can be done at room temperature solvent loss from these processes could conceivably be reduced to very low levels if the machinery and techniques are refined. Cotton fibers do not present the solvent retention problems that are encountered with polyester because they do not absorb and retain perchloroethylene. The solvent is quickly and easily removed from this fiber with heat.

Solvent desizing would substantially reduce or eliminate that portion of wastewater treatment typically resulting from the desizing process. The environmental advantage of this is similar to that which is obtained by recovery of polyvinyl alcohol (PVA) by hyperfiltration. Cost comparison of size recovery by solvent systems and hyperfiltration could not be made in this project because complete information on energy consumption in PVA desizing and recovery by hyperfiltration could not be obtained.

Loss of solvent to the atmosphere from solvent slashing and desizing of

polyester/cotton blends can be reduced to very low levels provided exposure of the fabric to the solvent is below the glass transition temperature of the polyester, machinery maintenance is adequate and carbon adsorption units are used to clean the air.

The solvent slashing and desizing systems currently available consume about the same total amount of energy as conventional aqueous systems. If the drying of the fabric between desizing and subsequent processes can be eliminated, energy consumption in the solvent process would be considerably less than in the aqueous process. This may be possible with 100% synthetic materials where the desizing and scouring processes might be combined. However, these processes cannot at present be combined if the material contains cotton since perchloroethylene is not effective in the removal of motes from the cotton. Therefore, solvent slashing and solvent desizing may be more readily and economically applicable to yarns containing only fibers such as polyester, nylon, acrylics, glass, etc. which do not contain the large amounts of nonfibrous impurities found in cotton.

The economic comparison of solvent slashing and desizing to aqueous slashing and desizing depends on the level of recovery and recycle of materials that can be achieved. Cost of energy, machinery and wastewater treatment are all much smaller than cost of materials in both aqueous and solvent sizing and desizing systems. Therefore, it is the cost of the size material and cost of solvent lost which largely determines the relative economics of the two types of processes. At total solvent losses of 0.072 pounds per pound of fabric processed and size material loss of 15% of the amount applied to the yarn, the costs of aqueous and solvent slashing and desizing are approximately equal. Much higher solvent and size recovery levels are feasible and if attained in practice would result in a significant cost advantage for solvent sizing and desizing compared to aqueous systems.

While this study was concerned primarily with solvent sizing and solvent desizing, the feasibility of aqueous sizing with hydroxypropyl cellulose and subsequent desizing in methylene chloride was also investigated. This type of process appears feasible and would circumvent the solvent sizing equipment cost that would be necessary for solvent slashing. The benefits of recovery and recycle of the size material should be available in this type of system.

SECTION 3

RECOMMENDATIONS

The technical and economic feasibility of sizing and desizing using organic solvents has been demonstrated on a laboratory scale. Since the economic success of woven fabric manufacturing depends greatly on the efficiency with which the yarn can be woven into fabric, in-plant demonstrations will be necessary to determine whether or not solvent slashing and desizing are commercially practical.

The studies reported herein pertain mainly to processing of cotton and blends of polyester with cotton. However, solvents such as perchloroethylene are very efficient in cleaning synthetic fibers such as polyester and not as effective for cleaning of cotton. Therefore, solvent slashing and desizing may be more readily applicable to yarns and fabrics containing only synthetic fibers. Further study is needed of solvent desizing of 100% synthetic fabrics wherein the desizing and scouring processes might be combined.

The data on solvent retention by polyester fibers reported herein is applicable to other processes such as scouring and finishing in which polyester is treated in perchloroethylene. The polyester fibers should be exposed to the solvent only at temperatures below the glass transition temperature of the fiber so that efficient removal of the solvent from the fiber can take place in the drying step.

The feasibility of slashing in aqueous medium and subsequently desizing in solvent medium should be studied in greater depth. The shift from water to organic solvent in slashing would require a high level of education and retraining of personnel since the process as now performed in the textile industry does not require the usage of sophisticated chemical and chemical engineering technology as would be required for solvent slashing. On the other hand, the solvent desizing process would be carried out in finishing plants where the personnel are trained in chemical handling techniques and in many instances have experience in the use of organic solvents. Therefore, the shift to use of solvents in desizing would not represent nearly as great a technology change as would be required for solvent slashing. Consequently, an aqueous slashing process that could be used in conjunction with solvent desizing could be a valuable development if economically and environmentally advantageous. Further study of a process of this type is needed.

SECTION 4

PROPERTIES OF SOLUBLE SIZING MATERIALS

EXPERIMENTAL PROCEDURE

Film Casting

Films were cast from dilute solutions in the appropriate solvent. The solution was poured on mercury in a square dish or spread uniformly on glass to allow the solvent to evaporate.

Tensile Properties

Strips of film 0.5 inches (1.27cm) wide and of measured thickness were broken on an Instron Tensile Tester. The gauge length was 3 inches, and the crosshead speed was 2 inches/minute.

Flexibility

Strips of film 1.0 inches (2.54 cm) wide were wrapped around a one-inch (2.54 cm) diameter glass rod. The test was performed at 20°C, 0°C and -10°C. If the film could be wrapped around the rod without cracking, it was rated as having passed the test.

Solubility

The length of time necessary for a 0.003 inch (3 mil) thick film to dissolve in the appropriate solvent at the appropriate temperature was determined.

Adhesion

Strips of the fiber substrate (cellophane or mylar polyester) 1 inch (2.54 cm) wide by 7 inches (17.78 cm) long were used for the adhesion tests. One (1) drop of the size material dissolved in the appropriate solvent at 5% solids concentration was placed on the end of one (1) strip of film. A second strip of film was placed over the first with a one (1) square inch overlap. The strips were placed under 10 pounds (4.54 kilograms) of pressure for 12 hours at 50°C to dry. The force necessary to separate the strips was determined using an Instron Tensile Tester.

SIZE SELECTION

Since the polymers commonly used as warp sizes for textile yarns are not

soluble in chlorinated hydrocarbon solvents such as perchloroethylene (perc), the initial phase of the research involved screening a large number of polymers for solubility in organic solvents. This screening resulted in the selection of ethyl cellulose (EC) of various types and grades for further study. The ethyl celluloses are soluble in perc in concentrations high enough to apply them to yarns in slashing but they are not soluble in water. Also selected for further study were several grades of hydroxypropyl cellulose (HPC). Hydroxypropyl cellulose is not soluble in perc but is soluble in dichloromethane or mixtures of 1, 1, 1-trichloroethane and isopropanol. HPC is also soluble in water at room temperature but precipitates when the water temperature rises to about 40-45°C. Therefore, a process using ethyl cellulose as the size material would require the use of perc for both size application and desizing. On the other hand, hydroxypropyl cellulose can be applied in sizing from either cold water or methylene chloride and also desized from the fabric using either water or the organic solvent.

SIZE FILM PHYSICAL PROPERTIES

All size materials are film forming agents. It is generally accepted that physical properties of films of size materials can be used to predict the effect of the size on yarn physical properties. The physical properties of the yarn in turn affect the performance of the yarn in weaving. Size material film properties which affect the properties of the yarn to which they are applied include tensile strength, elongation, flexibility and adhesion to the fiber being sized. Each of these properties was measured using films of ethyl cellulose and hydroxypropyl cellulose and compared to properties of films of polyvinyl alcohol (PVA) and carboxymethyl cellulose (CMC), typical spunyarn warp sizes.

The size material must possess sufficient tensile strength to bond together the individual fibers in a yarn. However, the strength of the size material must be low enough to allow the yarns to be separated at the slasher split rate without causing yarn breakage. Polyvinyl alcohol is known to cause splitting problems in certain cases, and the add-on of polyvinyl alcohol to the yarn must be low if fine yarns are to be sized successfully. The tensile strength of ethyl cellulose (Table 1) is probably satisfactory for warp sizing purposes. However, its high tensile strength implies that control of add-on may be necessary to enhance splitting at the loom rate. The tensile strength of hydroxypropyl cellulose appears ideal for warp sizing.

Sufficient elongation of the size materials is necessary if the material is to withstand the repeated cyclic stresses encountered by the yarn in weaving. A certain minimum elongation of 4-5% is desirable, but higher elongation is not essential. The elongation of hydroxypropyl cellulose is of the same order of magnitude as that of polyvinyl alcohol. The elongation of ethyl cellulose is similar to that of carboxymethyl cellulose, a commonly used warp size. While the elongation of ethyl cellulose is much lower than that of polyvinyl alcohol, the elongation of ethyl cellulose is probably adequate for good performance as a warp size.

A warp size must be easily removable from the woven fabric in desizing. The ease of removal of the size material is related to its solubility in the desizing medium. Polyvinyl alcohol is normally desized using large volumes of hot water. Films of ethyl cellulose dissolved more rapidly in perchloroethylene at 25°C than did films of polyvinyl alcohol in water at 100°C. Hydroxypropyl cellulose films dissolved as readily in water or dichloromethane at 25°C as did polyvinyl alcohol in water at 100°C. Heating of films of ethyl cellulose and hydroxypropyl cellulose at 110°C for 6 hours had little effect on the ability of the film to dissolve in the test solvent.

Adhesion of the size material is imperative since the size must bond together the fibers in the yarn. Further, the size material must adhere to both fibers if the yarn being sized is a blend. Ethyl cellulose does not adhere as well to either polyester or cellulose as does polyvinyl alcohol. Hydroxypropyl cellulose adheres well to both polyester and cellulose.

Flexibility of size materials is desirable since the size film on the yarn must withstand repeated bending as the yarn passes through the weaving elements. The flexibility of both ethyl cellulose and hydroxypropyl cellulose is excellent in the freshly cast film. Recovered ethyl cellulose and ethyl cellulose exposed to elevated temperatures for extended periods of time was brittle. The embrittlement of the ethyl cellulose can be attributed to oxidation.

Antioxidants can be added to ethyl cellulose formulations to alleviate the problem. However, even with an antioxidant present in the size film at a concentration of 1-3% by weight, the ethyl cellulose became brittle when heated for one (1) hour at 110°C.

DRYING CHARACTERISTICS OF HYDROXYPROPYL CELLULOSE

Since hydroxypropyl cellulose is not soluble in water at temperatures greater than 45-50°C, tests were performed to ascertain whether satisfactory films formed from solutions of HPC in water when heat is used to vaporize the water. Film formation by the size material on the yarn is necessary to achieve good size performance.

Thin coatings of a 5.0% aqueous solution of hydroxypropyl cellulose (HPC) were applied to glass plates. Individual plates were dried at different temperatures ranging from room temperature to 200°C. The appearance of the HPC during drying was observed and tensile properties of the resulting films were measured.

When the drying temperature was below 45°C, the HPC formed a clear film from the clear solution of HPC on the glass. At drying temperatures above 50°C, the HPC solution on the glass became cloudy, and a film formed over the top of the liquid. The solution dried gradually from edge to center of the glass plate leaving a clear film appearing virtually the same to the eye as the film deposited at temperatures below 45°C. However, the physical properties of the films deposited at high and low temperatures were not the same. The films formed at 85°C had tensile strength of about 1500

TABLE 1. PROPERTIES OF ETHYL CELLULOSE[1], HYDROXYPROPYL CELLULOSE[2], POLYVINYL ALCOHOL[3] AND CARBOXYMETHYL CELLULOSE[4]

PROPERTY	MATERIAL			
	Hydroxypropyl Cellulose	Ethyl-cellulose	Polyvinyl Alcohol	Carboxymethyl-Cellulose
Tensile Strength[5] (psi)	800-1300	3500-4900	3100	1000-1500
Elongation at Break[6] (%)	66-106	13-18	200-210	6-7
Resistibility of Film[7]	good	excellent	good	excellent
Adhesion to Mylar[8] polyester (psi/in)	19	8	16	
Adhesion[8] to cellophane (psi/in)	high[9]	9	high[9]	
Flexibility	excellent	excellent	excellent	excellent

[1]Hercules, Inc. Ethocel N-10

[2]Hercules, Inc. Klucel J

[3]DuPont Elvanol T-25

[4]Hercules, Inc. Warp Size Grade CMC

[5]Range of averages for various films rounded to nearest 100 psi

[6]Range of averages measured for various films rounded to nearest 1.0%

[7]In water for CMC and PVA, para for ethyl cellulose, water and methylene chloride for hydroxypropyl cellulose.

[8]Average of a minimum of 10 specimens

[9]Adhesive bond is greater than strength of cellophane which is approximately 1 pounds for the 1 inch wide strip used in the test.

psi and elongation of about 22%, while the films formed at room temperature had tensile strength of about 800 psi and elongation of about 42%. Therefore, high drying temperatures apparently do not prevent the HPC from forming films having good properties.

SECTION 5

PREPARATION OF SOLVENT SIZED YARNS

The performance of yarns in weaving depends on the presence of certain physical properties of the yarn. Among these are yarn tenacity, elongation at the break and abrasion resistance. The required level of these properties for good weaving performance depends on the type of yarn being processed.

Evaluation of these properties was made by comparison of yarn sized with the experimental materials to yarns sized with the conventional aqueous size polyvinyl alcohol which is commonly used to size polyester/cotton blend yarns. One of the yarns was 100% cotton, 22's cotton count and the other was 50/50 polyester/cotton intimate blend, 22's cotton counts.

EXPERIMENTAL PROCEDURES

Size Applicators

Two separate techniques were used to apply the experimental size materials to the yarns. The applications for the preliminary tests were made to a yarn passed through a single yarn sizing apparatus. A schematic diagram of the apparatus is shown in Figure 2. The supply package was a cone of yarn. After passing through the size solution, the yarn was wiped as it passed through a slit in a wool felt pad. In tests requiring a hot size solution, the size container was heated on a hot plate during the size application. After the size application, the yarn was dried during passage through a well-ventilated chamber. The sized yarn was taken up on a spool at a rate determined by the drying capacity of the device. The wet pickup in this single yarn applicator was approximately 300%. Therefore, the concentration of size material required in the size solution was much lower than that used for a warp subjected to squeezing by rubber covered rolls as is typical in slashing.

The second device used for the size applications was a laboratory scale slasher which produced a sized warp one inch (1 in, 2.54 cm) wide (Figures 3 & 4). The supply package was a beam 4 3/8 inches (11.1 cm) wide. The yarn passed under a single immersion roll in an indirectly heated size box and was squeezed between a bottom brass roll and a top viton roll (75 durometer Shore A, cold). The squeeze pressure was regulated by spring loading each end of the top squeeze roll. Hot air was circulated through the drying chamber to remove the solvent or water from the warp. All warps consisted of seventy-five (75) ends. Prior to take-up on the loom beam, the yarn was split by a single lease rod and passed through an expansion comb with three (3) ends per dent. Tension on the warp was controlled via a spring loaded compensator roll which activated limit switches to increase or decrease the take-up speed as

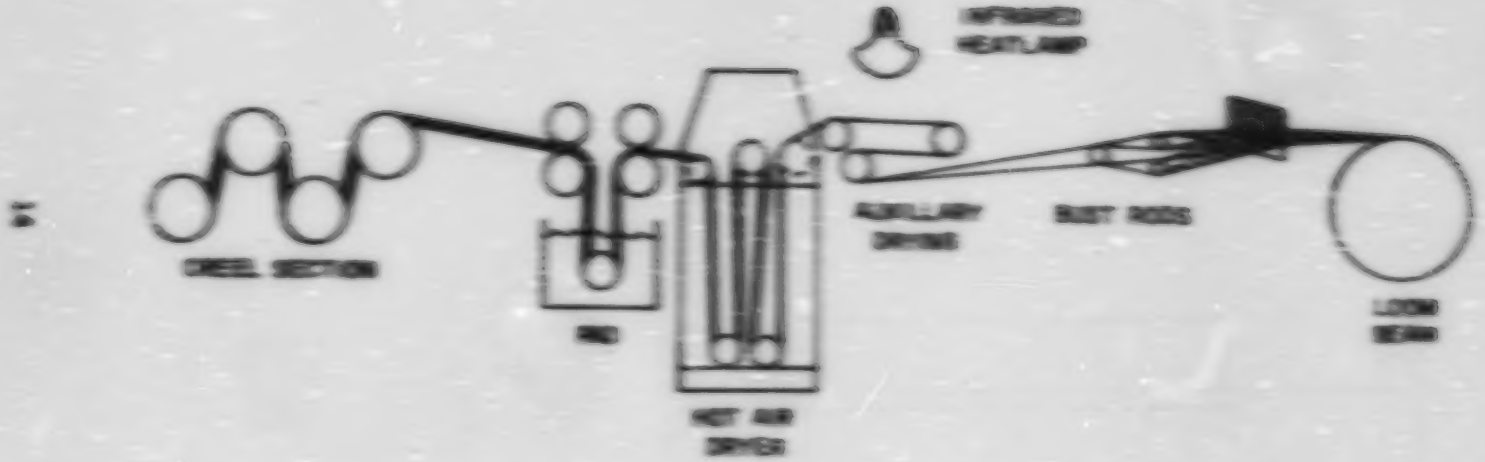
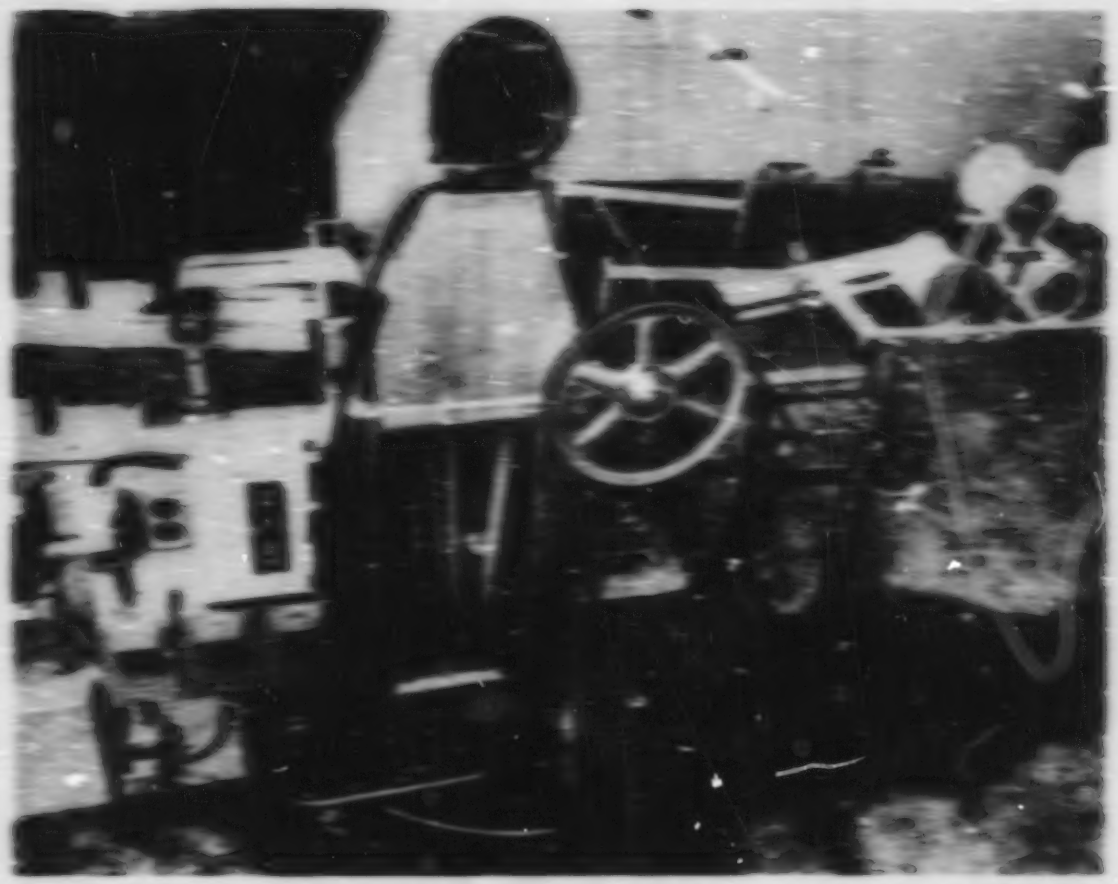


FIGURE 1. [illegible]



required. The yarn speed at the size box squeeze rolls was constant.

Size Add-on Determination

The size was removed from a previously dried and weighed sample by soxhlet extraction using an appropriate solvent. The size add-on and content were calculated by the usual methods.

Tensile Properties

Breaking tenacity and elongation of the yarns was measured on the Instron Tester using 10 inch (25.4 cm) gauge length and 2 inches/min (5.08 cm/min) crosshead speed.

Abrasion Resistance

The tendency of the yarns to withstand cyclic abrasive forces was measured using a Taylor Abrasion Tester. The number of cycles of the tester required to cause the test yarn to break was determined.

Size Location

Sized and unsized yarns were examined using a Scanning Electron Microscope and a light microscope to assess the uniformity of the coating of the size material on the yarn and to determine the degree of penetration of the size material into the yarn.

YARN TENACITY

The breaking tenacity of the yarns was increased by addition of the size materials. The data in Table 2 show that the break factor of 100% cotton yarns was greater when the add-on of size material was higher regardless of which size material was used and whether the system used solvent or not. At similar add-on levels, the ethyl cellulose applied from perchloroethylene and the hydroxypropyl cellulose applied from water at room temperature increased the yarn tenacity by about the same amount as did the polyvinyl alcohol applied by conventional squeeze techniques.

The increase in tenacity upon sizing the 50/50 polyester/cotton blend yarns was much smaller than obtained on the 100% cotton yarns. However, the three size materials caused comparable increases in the tenacity of the 50/50 blend yarns.

YARN ELONGATION

The elongation at the break of all of the sized yarns was less than that of the unsized yarns (Table 3). This is the typical result of slashing. However, the elongation of the 100% cotton yarns sized in the solvent system with ethyl cellulose was significantly higher than that of similar yarns sized in water with polyvinyl alcohol using conventional techniques. The retention of elongation in the sized yarn is an important characteristic with regard to weaving performance of the yarns. This difference in elongation between sol-

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vent and aqueous sized 100% cotton yarns did not occur to the same extent in the 50/50 polyester/cotton blend yarns. The 50/50 blend yarns decreased in elongation by about the same amount regardless of whether the solvent or aqueous sizing system was used.

When hydroxypropyl cellulose was applied from water at room temperature, the resulting 100% cotton and 50/50 blend yarns had about the same elongation as the corresponding control yarns sized with PVA.

ABRASION RESISTANCE

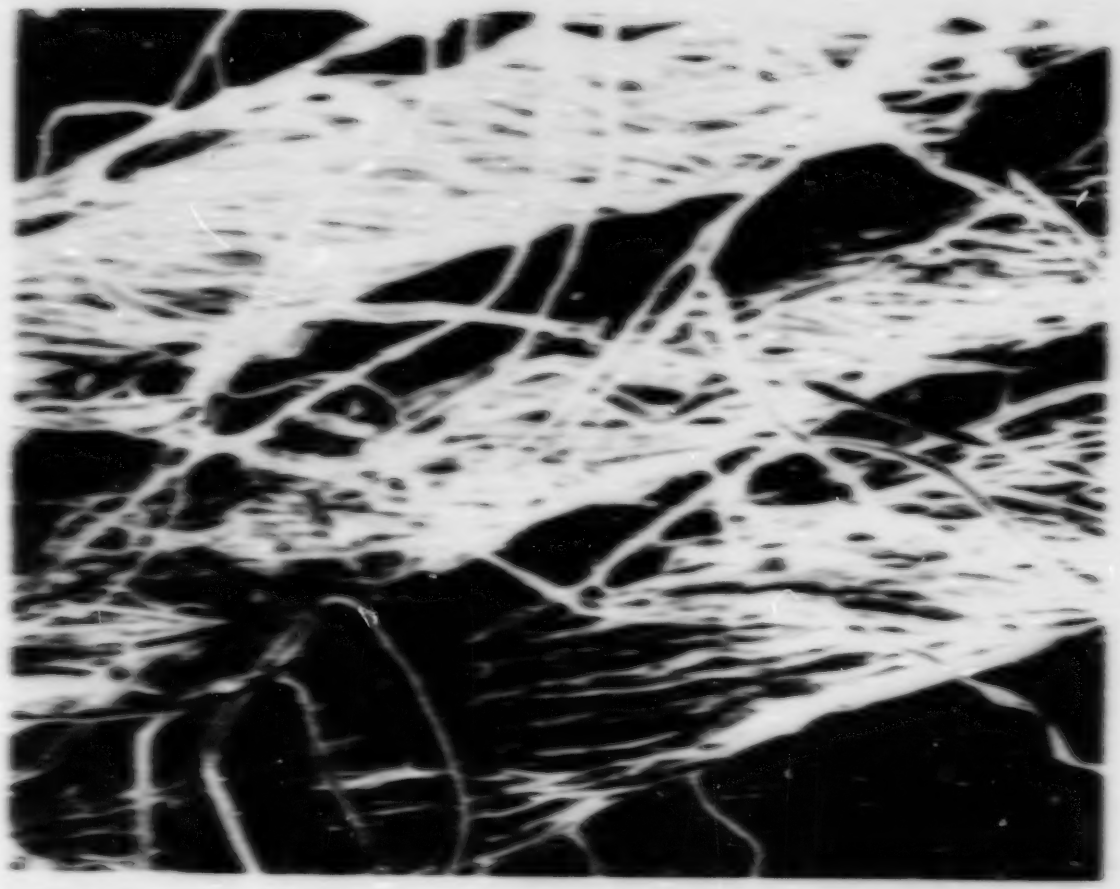
The number of abrasive cycles to cause breakage of 100% cotton yarns on the Duplan Cohesion Tester increases as the size add-on is increased as indicated by the data in Table 4. Yarns sized with PVA in a conventional aqueous system gave better results in this test than did yarns sized with ethyl cellulose from zero or hydroxypropyl cellulose from water at room temperature. Since the film properties and adhesive characteristics of ethyl cellulose and hydroxypropyl cellulose are comparable to those of polyvinyl alcohol, these abrasion results indicate that additional developments in the size formulation and/or application techniques are needed. For example, lubricants commonly used in aqueous slashing systems are not suitable for solvent formulations or cold aqueous sizing so the experimental formulations contained no lubricants. Studies of the effects of lubricants on properties of films of HPC were conducted late in the project but were inconclusive.

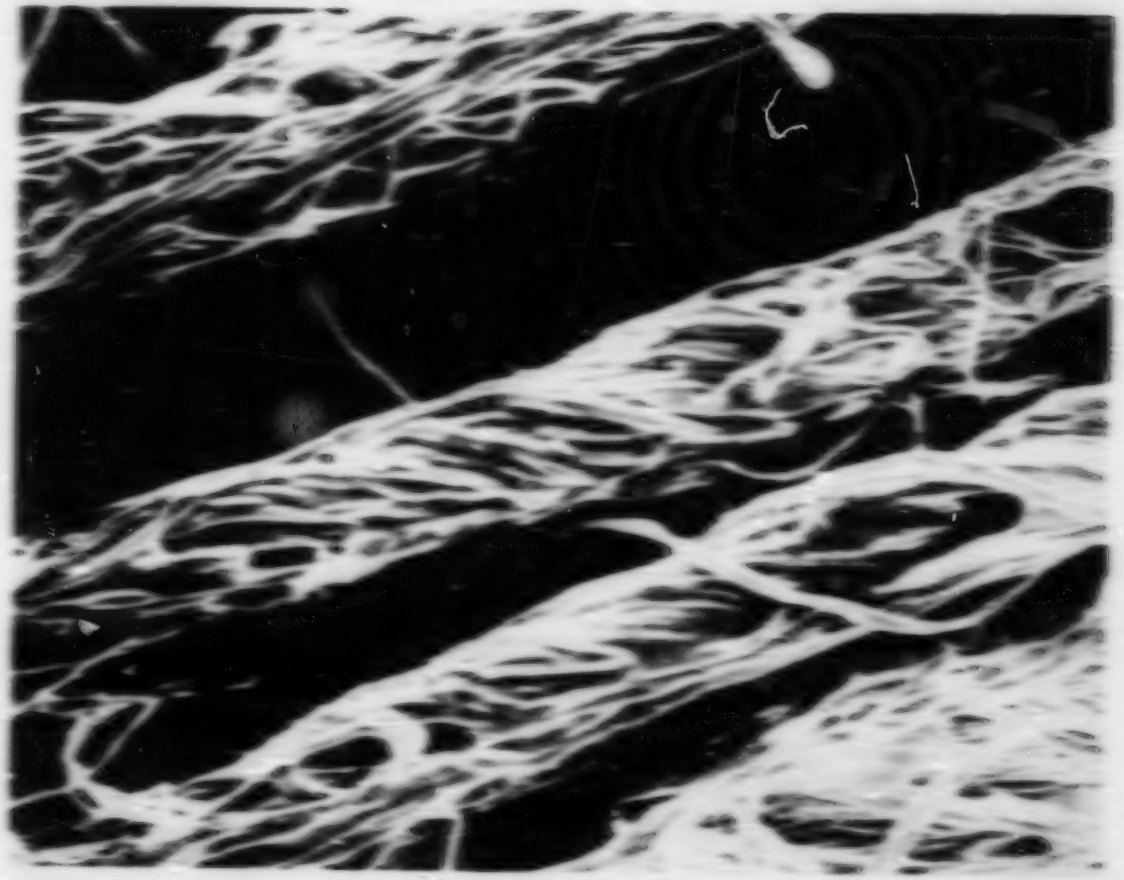
SIZE LOCATION

The scanning electron photomicrographs in Figures 5,6, & 7 are representative of the appearance of polyvinyl alcohol, ethyl cellulose and hydroxypropyl cellulose on the yarns. In Figure 5 are 100% cotton unsized yarns (first three on the left) and yarns containing about 15% by weight of ethyl cellulose (last four on the right). The size coating is continuous and uniform. The size on the 50/50 blend yarns appeared much the same as on these 100% cotton yarns. In Figure 6 are three 100% cotton yarns containing about 10% by weight of polyvinyl alcohol. The fibers protruding from the surface of the yarn are not encapsulated by the size material as they are with the ethyl cellulose. In Figure 7 are 100% cotton yarns containing about 13% by weight of hydroxypropyl cellulose. As was the case with the ethyl cellulose, the hydroxypropyl cellulose uniformly coats the yarn surface and almost completely encapsulates the protruding fibers binding them to the yarn bundle. The difference in the surface appearance of yarns sized with PVA compared to EC or HPC may be the result of the much lower viscosity of the PVA size solution. The surface characteristics of the 50/50 blend yarnswere very similar to that of the 100% cotton yarns in all cases when the same size was applied.

Penetration of the size materials into the yarn was assessed by examination of cross sections of the yarns using a light microscope. Dyes were added to the size formulas to aid the identification of the size material in the yarn cross section. There was no apparent difference in the depth of penetration of the three size materials into the yarn bundle. The PVA applied from hot water, the EC applied from perchloroethylene at room temperature and the HPC applied from water at room temperature all penetrated about 1/3 to 1/2 the distance from the surface to the center of the yarns.

[illegible]





SECTION 6

WEAVING OF SIZED YARNS

All yarn samples were woven on a Draper E model loom at 175 pick insertions per minute. Initially the test yarns were entered into the loom as a strip approximately one inch wide on the left selvage of an 18-inch wide fabric. Later, more test yarns were entered until finally the entire warp was made up of yarns sized in this study. The yarns were entered into four harnesses weaving a birdseye diamond weave as shown by the draft in Figure 8. Yarns were drawn 4 ends per dent into a 17 dent reed; and, a 50-tooth pick gear was used. This gave an on-the-loom construction of 68 ends per inch and 50 picks per inch. Off the loom, the average construction was 72 ends per inch and 57 picks per inch which gave a fabric weight of about 5 ounces per square yard.

The results of the weaving trials are shown in Table 5. All sample warps performed within reasonable breakage rates. In general, the warps sized with PVA performed somewhat better in weaving than did the warps sized with ethyl cellulose or hydroxypropyl cellulose. This behavior is understandable based on the abrasion resistance figures previously discussed. Attempts to lubricate the warps with hydrophilic carbowax lubricants resulted in poorer weaving performance in PVA sized warps. Since the strength, elongation and adhesion to polyester and cellulose of ethyl cellulose and hydroxypropyl cellulose are adequate, their performance in weaving can probably be improved by optimizing the size formulation, add-on level and application techniques.

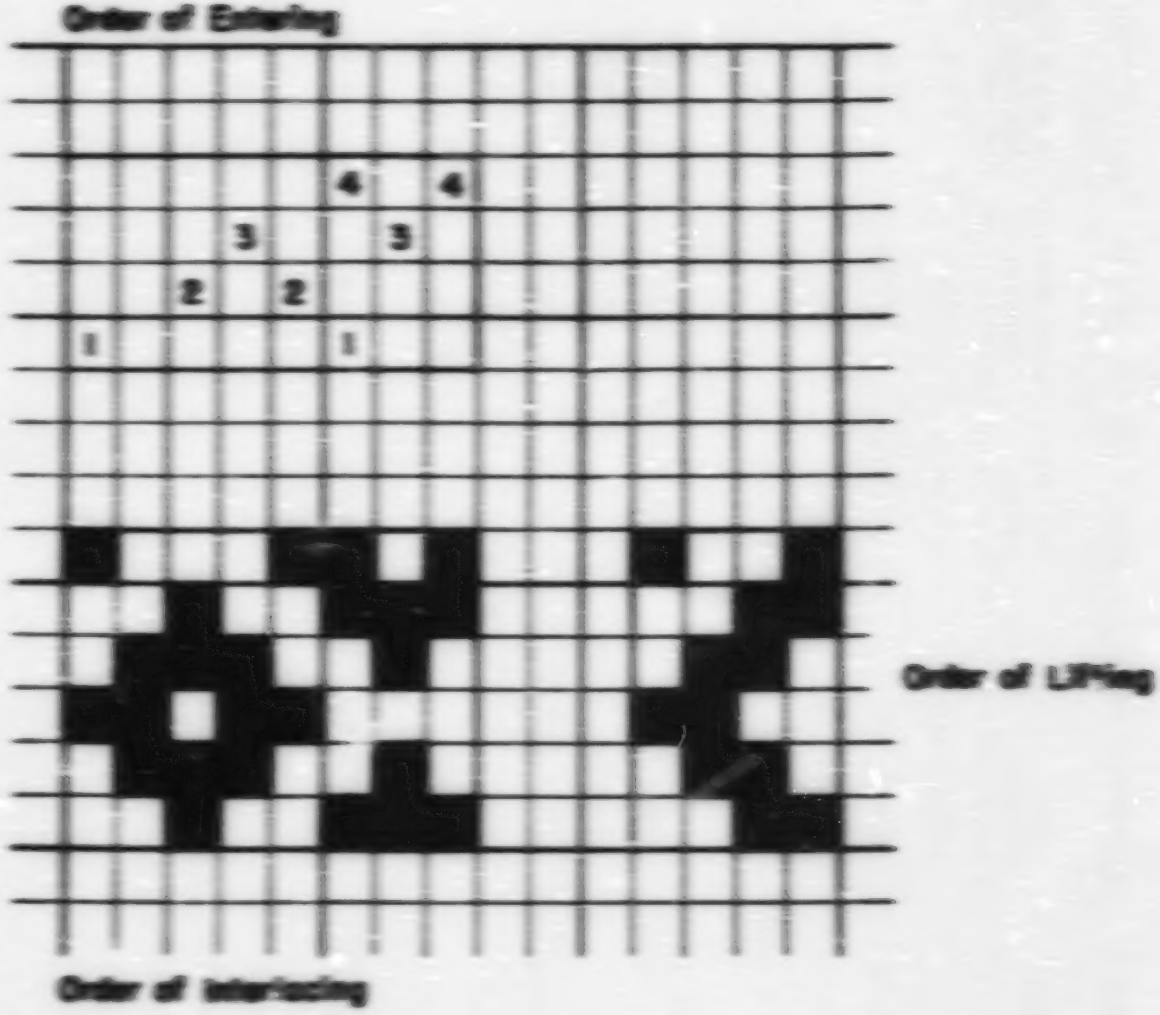

Order of Entering
4
4
3
3
2
2
1
1
Order of Lifting
Order of Interlocking

FIGURE 1. [illegible]

TABLE 5. END BREAKAGE RATES FOR YARNS SIZED WITH VARIOUS SIZING MATERIALS.

Sizing Material	Fiber Content	Percent Add-on	Total Weaving Minutes	Average Breaks Per Loom Hour
PVA	100% cotton	7.4	300	0.3
HC H-10	100% cotton	12.8	300	0.6
HPC-J[1]	100% cotton	14.5	300	2.1
HPC-E[2] (with wax)	100% cotton	17.4	400	4.0
HPC-E (w/o wax)	100% cotton	17.0	400	1.4
PVA	50/50 PE/cotton	7.0	300	0.0
HC H-10	50/50 PE/cotton	11.13	300	2.7
HPC-J	50/50 PE/cotton	11.4	300	1.5
HPC-E (wax)	50/50 PE/cotton	13.0	300	3.0
HPC-E (no-wax)	50/50 PE/cotton	12.5	300	1.5

[1]Hercules, Inc. - Klemm, J.

[2]Hercules, Inc. - Klemm, E.

SECTION 7

FABRICS CONTAINING SOLVENT SIZED YARNS

PHYSICAL PROPERTIES

Woven fabric samples were subjected to various strength and abrasion tests. Ten determinations were performed in the warp and the filling direction for each sample and each test. The averages for strength and elongation as determined on the Instron for a one-inch ravelled strip are shown in Table 6. It can be seen that there is no significant difference between fabric samples sized with the different sizing materials of this study. The Instron was equipped with a "D" cell and set for 3-inch gauge, 100 pound full scale load, 12 inches per minute crosshead rate and 50 inches per minute chart speed.

Tear strengths were determined for warp and filling directions on the Elmendorf Tear Tester. These data are given in Table 7 except for the PVA sized samples which would not tear at the maximum load of this test. The results obtained for the samples which did tear are not significantly different from one sample to the other.

The Stoll Flex Abrader with a three-pound tension weight and a one-and-one-half pound head weight was used to determine fabric abrasion resistance. These results are given in Table 8 where it is shown that the PVA sized warps produced fabrics with much greater abrasion resistance as measured by this particular test. The other samples were essentially equal in terms of resistance to abrasion.

DESIZING, BLEACHING, DYEING

Samples of the 50/50 polyester/cotton blend fabric were desized, bleached and dyed to ascertain the effect of solvent sizing and desizing on these subsequent processes. A sample sized with PVA was desized using boiling water. A sample sized with ethyl cellulose was desized by washing for 30 seconds in each of two portions of clean perchloroethylene. These two fabrics were then bleached simultaneously with hydrogen peroxide and later dyed in a common bath, first with C.I. Disperse Blue 3 for the polyester and then with C.I. Direct Blue 1 for the cotton. The reflectance curves of the bleached and dyed samples were measured.

The water absorbency of the aqueous desized sample (PVA) was greater than that of the solvent desized sample (E). The aqueous desized sample (PVA) was slightly whiter after bleaching than was the solvent desized sample (E). The dyeability of the two samples was essentially the same. The difference in reflectance of the samples after dyeing was about the same as the difference in reflectance of the samples after bleaching. The solvent desized fabric proces-

TABLE 6. ONE-INCH RAVELED STRIP DISPERSION AND ABRASION FOR FABRICS SIZED WITH VARIOUS SIZING MATERIALS.

Sizing Material	Fiber Content	Filling Direction Elongation (%)	Filling Direction Strength (lbs)	Warp Direction Elongation (%)	Warp Direction Strength (lbs)
PVA	cotton	12.8	53.9	12.1	62.7
BE M-10	cotton	13.1	53.3	10.0	54.5
HPC-J[1]	cotton	11.4	46.4	11.8	59.1
HPC-E[2]	cotton	11.9	49.7	11.3	60.9
PVA	PE/cotton	14.0	59.0	15.8	85.0
BE M-10	PE/cotton	13.6	51.6	16.1	87.0
HPC-J	PE/cotton	12.4	53.0	17.0	84.6
HPC-E	PE/cotton	12.1	49.9	15.7	87.7

[1]Hercules, Inc. Klucel J
[2]Hercules, Inc. Klucel E

TABLE 7. TEAR STRENGTH FOR FABRICS SIZED WITH VARIOUS SIZING MATERIALS AS DETERMINED BY THE ELMENDORF TEAR TESTER

Sizing Material	Fiber Content	Filling Strength (g)	Warp Strength (g)
BJ M-10	cotton	3500	3470
HPC-J[1]	cotton	3540	3690
HPC-E[2]	cotton	3339	4021
BJ M-10	Poly/cotton	3596	5863
HPC-J	Poly/cotton	2897	6193
HPC-E	Poly-cotton	3164	6307

[1]Hercules, Inc. Klucel J
[2]Hercules, Inc. Klucel E

TABLE 8. ABRASION RESISTANCE OF FABRIC BARRIER SYSTEMS WITH VARIOUS SIZING MATERIALS.

Sizing Material	Fiber Content	Filling Abrasion Cycles	Warp Abrasion Cycles
PVA	cotton	1330	3567
HE N-10	cotton	1114	793
HPC-J[1]	cotton	955	1133
HPC-E[2]	cotton	933	1076
PVA	PE/cotton	2394	7230
HE N-10	PE/cotton	589	1147
HPC-J	PE/cotton	1325	1298
HPC-E	PE/cotton	914	1297

[1]Hercules, Inc. Klucel J
[2]Hercules, Inc. Klucel E

and satisfactorily and no difficulties in bleaching and dyeing were encountered.

CHEMICAL AND PHYSICAL EFFECTS

The possibility of an effect of perchloroethylene on the properties of polyester fiber was investigated in order to insure that no significant changes would occur in the fiber during solvent slashing.

Experiments were performed to observe the effect of solvent on the surface characteristics of the fibers. Polyester fabric was heated in perchloroethylene at 121°C for 15 minutes. The fabric was allowed to air dry for 15 minutes. These specimens were then coated with a gold alloy using vacuum deposition techniques. The coated specimens were then observed by scanning electron microscopy. Photographs of the fiber surfaces were taken at 500X and 1000X magnification. These surfaces were then compared with the surfaces of similar polyester fibers not subjected to the solvent bath. These experiments indicated no significant change in the surface of the polyester fibers.

The thermal properties of the polyester fibers before and after treatment in the solvent bath at 121°C were compared utilizing thermal gravimetric analysis and differential scanning calorimetry. These experiments indicate no significant change in the thermal properties of the polyester fabric with the exception of the effects caused by solvent expiration from the fiber as the fibers are heated. There appeared to be no change in the glass transition temperature or melting point of the fiber.

SECTION 8

SOLVENT REMOVAL [illegible]

The use of organic solvents in textile dyeing and finishing has been explored by industry and independent researchers extensively for the past several years. This research was prompted by the need for an alternative solvent to replace the traditional solvent, water. This interest in solvent processing dates back earlier than 1937 when a Celanese patent (1) referred to the use of organic solvents for continuous dyeing. In other early research, Garret (2,3) described the use of trichloroethylene vapor to fix disperse dyes on polyester and cellulose acetates. More recently, solvent processing has been demonstrated to be economical in the removal of oils from knitted fabrics.

As an outgrowth of studies (4) on dyeing rates from perchloroethylene solvent with polyester fibers, a new study was initiated in an attempt to define the various economic, processing conditions and materials and also the environmental significance of a solvent slashing and desizing operation for cotton/polyester fabrics. One of the obvious questions to be answered was the effect and extent of solvent retention by the polyester fibers. The answers here are important from two basic standpoints; the first is the economics of solvent recovery and the second, is an environmental question of the release of solvent from the fiber after processing has been completed.

Previous reports have indicated that retention of perchloroethylene by polyester fiber may be of concern. Dyland, et. al., (5) gave a brief indication of the drying conditions of polyester under conditions of superheated perchloroethylene. His reported data showed some information on vapor concentration at various processing conditions over short drying time (seconds). More recently, Brokmann (6) gave retention data for chlorinated solvents in fabrics under conditions of dry-cleaning processing. These data again indicate some retention of solvent by polyester.

A more in depth study was performed to provide a better description of the total retentions and rates of loss of chlorinated solvents from polyester fabric. This information was necessary for a thorough economical and environmental evaluation of solvent slashing and desizing processes for fabrics containing polyester fibers.

EXPERIMENTAL

The fabrics used in this study were obtained from Test Fabrics, Inc. The fabrics were 100% polyester, one was heat set, one was without heat set. Solvents used were of reagent grade. Thermal analysis experiments were performed using a DuPont Thermogravimetric Analyser.

The fabrics used were exposed to solvent in the following manner. In order to determine the retention of solvent as a function of temperature the following procedure was followed. Fabric pieces which had been previously taken to constant weight were immersed in a solvent bath which was maintained at the desired temperature. The solvent and fabric were stirred at regular intervals. After immersion in the solvent bath for 15 minutes, the fabric was removed and allowed to dry at room temperature for 10 minutes. This allowed surface solvent to evaporate. The fabric was then weighed to determine the percent retention of solvent within the fiber. After weighing, the fabric was allowed to expire solvent under ambient room conditions and was reweighed at various time intervals. This experiment therefore gave data of percentage retention versus time. Different bath temperatures were employed and the procedure above repeated in order to determine the retention of solvent under these conditions.

A second experiment was devised in order to determine the rate of removal of solvent from the fiber at various drying temperatures and under flow conditions. Small pieces of fabric were heated in the solvent for 1½ minutes at the boiling point of the solvent. This gave a maximum value for initial retention. The fabrics were then allowed to dry as before. The dry samples were then placed in the Thermal Gravimetric Analyser. The sample was then heated under nitrogen gas flow and at isothermal conditions. The percent weight (solvent) loss of the sample versus time was obtained. The experiment was performed in triplicate at several temperatures.

The two solvents tested were perchloroethylene and dichloromethane.

RETENTION OF PERCHLOROETHYLENE

In any solvent process the economics will be partially dependent on the ability to recover the solvent efficiently. One possible pathway for solvent loss in finishing of polyester or other synthetic fibers is by retention in the fibers.

The retention of perchloroethylene by two specific polyester fabrics as a function of temperature is shown in Figure 9 and tabulated in Table 9. These data indicate the temperature dependent nature of perchloroethylene sorption by polyester. The curves in Figure 9 show that between bath temperature of 60°C and 100°C, there is direct relationship of retention with temperature. After 100°C these data indicate a saturation level. Obviously, if the processing temperature is maintained below 60°C, there will be little or no retention of solvent. At room temperature (22°C) there is no significant retention of perchloroethylene in the fabric. Therefore, solvent processing at this temperature would cause no solvent loss by retention.

REMOVAL OF PERCHLOROETHYLENE

Further experiments were conducted to determine the removal behavior of the solvent from polyester fabric. Data showing the retention of perchloroethylene from the fabric at room temperature as a function of drying time are presented in Figure 10. These data show a gradual reduction of solvent in the fabric. The initial concentrations were those achieved by treating the fabric

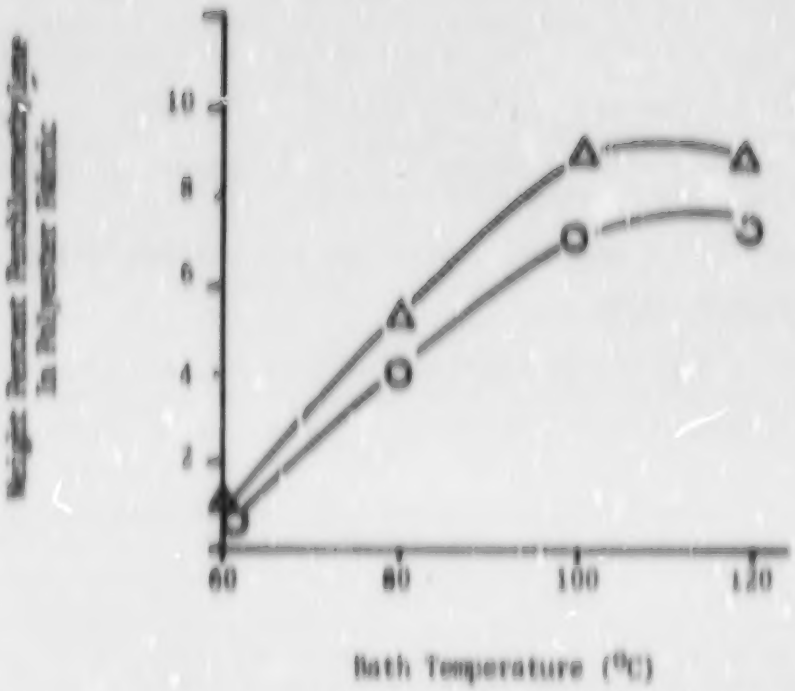


FIGURE 9. EFFECT OF BATH TEMPERATURE ON THE RETENTION OF PHOSPHORUS IN POLYESTER FABRICS AFTER AIR DRYING AT AMBIENT TEMPERATURE WITH △ AND WITHOUT ○ HEAT SET.

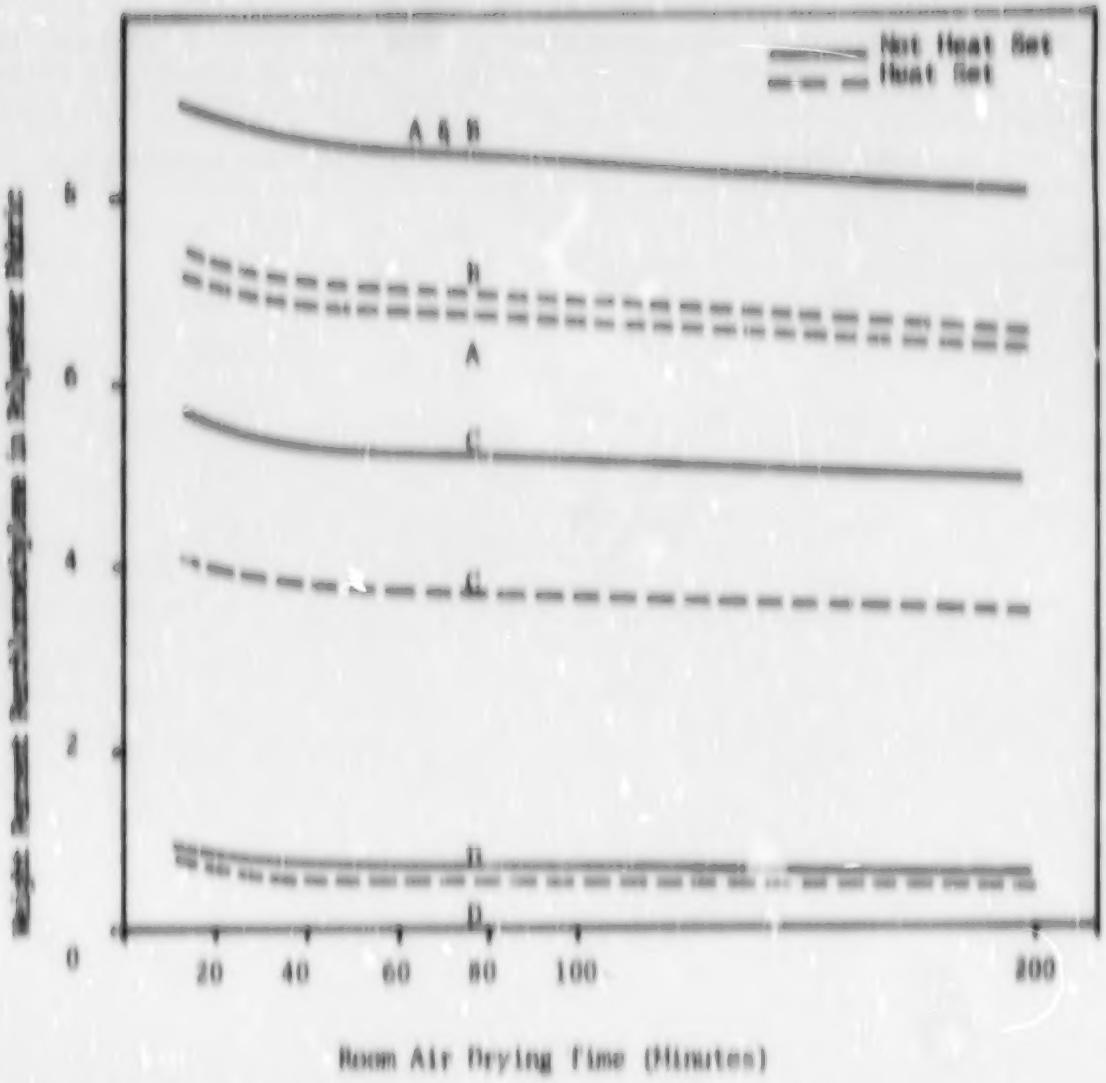


FIGURE 13. EFFECT OF PERCHLOROETHYLENE BATH TEMPERATURE ON THE RETENTION OF PERC IN POLYESTER FABRICS WITHRAP AND WITH HEAT-SET. BATH TEMPERATURES: A-121°C, B-100°C, C-80°C, D-60°C. FABRIC IMMERSION TIME: 15 MINUTES.

TABLE 9. [illegible]

Temperature	Weight Percent Perchloroethylene	
°C	Heat Set	W/O Heat Set
22	< 0.01	< 0.01
60	0.6	0.8
90	3.9	5.4
100	7.0	8.8
120	7.2	8.8

at different bath temperatures. The rates of loss of solvent vs. time at constant temperature are the same and therefore independent of initial retention level in the fabric. Also, these data indicate the slow loss of the retained solvent under ambient drying conditions.

PERCHLOROETHYLENE REMOVAL vs. DRYING TEMPERATURE

As shown by the ambient condition data, elevated temperatures will be necessary to remove the solvent from fabric after it has been retained. Polyester fabric was treated at the maximum perchloroethylene bath temperature (121°C) in order to achieve a high level of retention. This fabric was then heated isothermally using a thermogravimetric analyzer as previously described. The isothermal conditions were set at different levels to obtain the rates of removal and removal behavior at these temperatures. Table 10 shows the rates of removal, in percent per minute, of the perchloroethylene from polyester fabrics. The removal behavior of the perchloroethylene indicated two different curves. An initial, very rapid, removal followed by a much slower removal. This is reflected in the initial and final rate data shown in Table 10. As expected the initial rates of removal of solvent are highly temperature dependent. At 60°C the removal is slow so that one cannot distinguish between the initial and final rate.

RETENTION OF PERCHLOROETHYLENE AFTER DRYING

The information shown in Table 11 is of more significance to this project than the previously discussed rates of removal. This table gives the retention of solvent after 2.5 minutes and 5.0 minutes of drying at the indicated temperatures. These data are also plotted in Figures 11 and 12 for easier interpretation. It is shown that at the lower temperatures most of the retained solvent is still in the fabric after 5 minutes of drying and that a significant amount of the retained solvent is present after 2.5 minutes of drying at the higher temperature, 120°C. Therefore, under normal industrial processing conditions retained perchloroethylene would not be efficiently removed.

Thus, the temperature of perchloroethylene solvent in the finishing of polyester fiber or fabric must be maintained low enough to prevent the solvent from entering the fiber and being retained. Low treatment temperatures were therefore used in the sizing experiments which were successfully conducted in this project so that the drying of the yarn or fabric could be accomplished. At elevated drying temperatures the solvent would be evaporated from the surface before the fabric temperature is raised high enough to allow significant sorption.

With the data described herein one should be able to calculate any of the retention information needed for any type of solvent finishing of polyester fiber or fabric using perchloroethylene solvent.

DICHLOROMETHANE REMOVAL

The rates of removal of dichloromethane from the two polyester fabrics previously described was determined at drying temperatures ranging from 40°C

TABLE 10. RATES OF REMOVAL OF PERCHLOROETHYLENE FROM POLYESTER FABRICS AT VARIOUS DRYING TEMPERATURES.

Temperature °C	Rate of Removal (%/Min)			
	Heat Set		W/O Heat Set	
	Initial	Final	Initial	Final
60	--	0.03	--	0.03
80	1.0	0.03	1.1	0.03
100	2.4	0.02	2.5	0.03
130	4.5	0.01	4.1	0.02

TABLE 11. RETENTION OF PERCHLOROETHYLENE IN POLYESTER FABRIC AFTER DRYING THE PERC ENTRAINED FABRIC FOR 2.5 AND 5.0 MINUTES AT VARIOUS TEMPERATURES.

Temperature	2.5 Minutes		5 Minutes	
°C	Heat Set	W/O Heat Set	Heat Set	W/O Heat Set
60	7.7	8.3	7.2	7.8
80	6.0	6.8	5.2	6.0
100	4.2	5.3	3.0	4.0
130	1.8	2.4	0.9	1.6

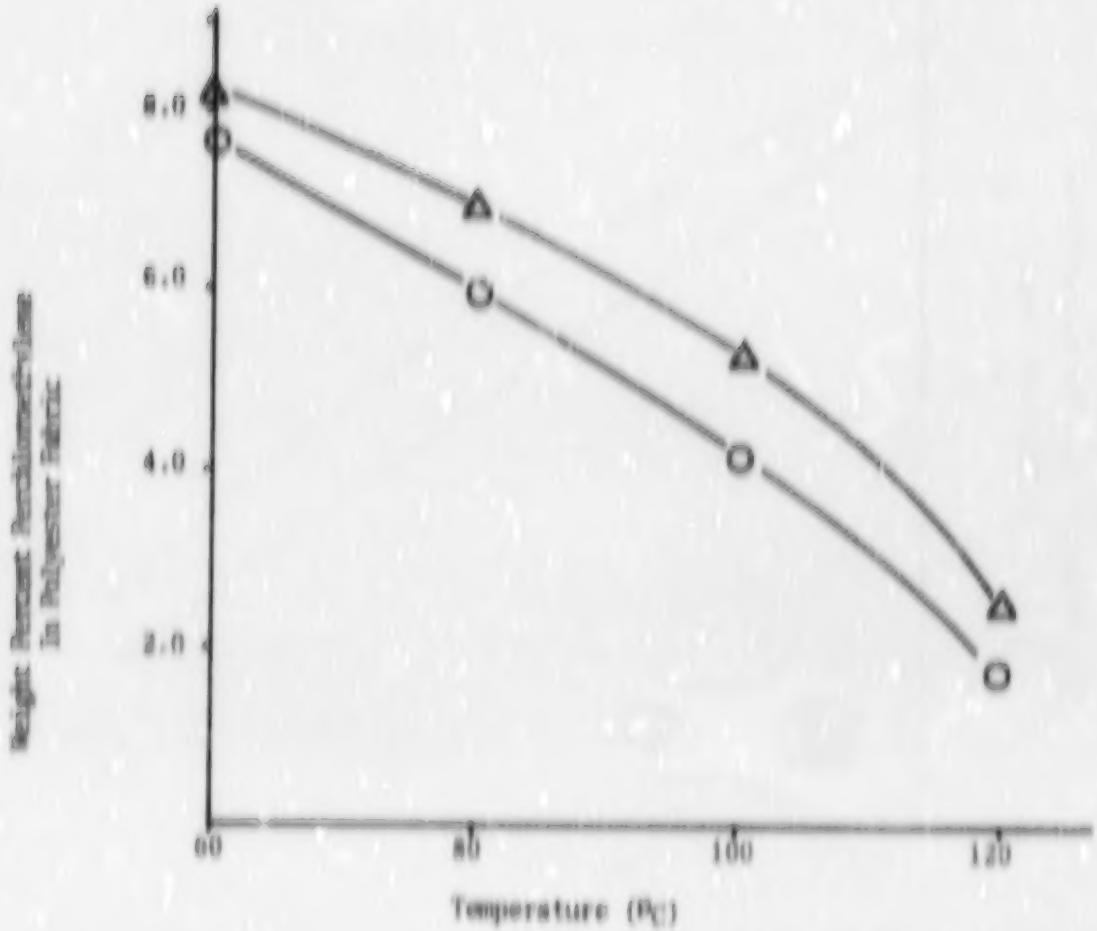


FIGURE 11. WEIGHT PERCENTAGE OF PERCHLOROETHYLENE RETAINED BY POLYESTER FABRIC AFTER DRYING FOR 2.5 MINUTES AT VARIOUS TEMPERATURES WITH HEAT SET ○ WITHOUT HEAT SET △

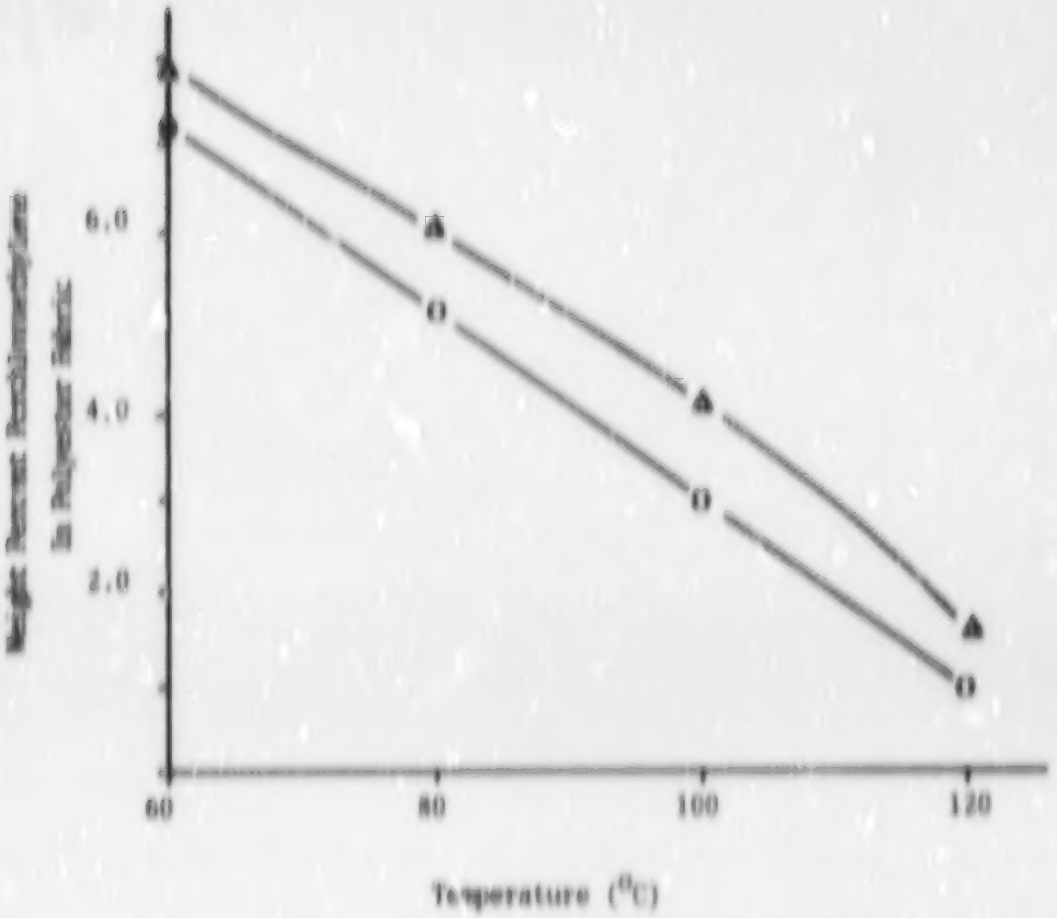


FIGURE 12. WEIGHT PERCENTAGE OF PERCHLOROETHYLENE RETAINED BY POLYESTER FABRIC AFTER DRYING FOR 5.0 MINUTES AT VARIOUS TEMPERATURES WITH HEAT SET O WITHOUT HEAT SET ▲

to 130°F. These data are shown in Table 12. These data again indicate a two slope behavior with the initial slope very temperature dependent.

The retention of dichloromethane after drying intervals of 2.5 and 5.0 minutes are shown in Table 13. These data show that there is significant retention of the solvent even at temperatures well above the solvent boiling point. The use of the low boiling solvent therefore shows no particular advantage over perchloroethylene as far as its retention behavior is concerned.

SUMMARY

The sorption and retention behavior of solvents by polyester has been shown to be dependent on the solvent bath temperatures and on the drying temperatures. At high bath temperatures there is a large quantity of solvent sorbed, greater than 9 percent. At low bath temperatures, for example room temperature, there is little or no perchloroethylene absorbed. The rates of removal of the solvent from the fiber were higher at higher temperatures and lower at low temperatures. The obvious conclusion is that in order to avoid solvent retention the solvent must be prevented from entering the fiber. This can be accomplished by using low bath temperatures (room temperature) and by removing the surface solvent rapidly, preventing penetration of the solvent into the fiber during drying.

Prevention of retention of solvent in the fiber removes the danger of air pollution by expiration of the solvent after the fabric has left the processing facility.

The loss of solvent would have a significant effect on the economics of the process. As shown in the economic evaluations of the process, material costs are important. However, from the information on solvent retention presented herein, the loss of solvent through retention can be avoided to such a degree as to make the loss insignificant.

TABLE 12. RATES OF REMOVAL OF DICHLOROETHANE FROM POLYESTER FABRIC, (FABRIC SATURATED AT 41°C)

Drying Temperature °C	Rate of Removal - %/Minute			
	Heat Set		W/O Heat Set	
	Initial	Final	Initial	Final
40	0.2	0.036	0.2	0.033
60	1.2	0.021	0.9	0.035
80	1.4	0.008	1.2	0.014
100	2.1	0.001	2.5	0.004
120	5.6	~ 0	4.5	~ 0

TABLE 13. RETENTION OF DICHLOROETHANE IN POLYESTER FABRIC AFTER DRYING THE SATURATED FABRIC FOR 2.5 AND 5.0 MINUTES AT VARIOUS TEMPERATURES.

Temperature	Retention - Weight %			
	2.5 Minutes		5.0 Minutes	
	Heat Set	W/O Heat Set	Heat Set	W/O Heat Set
60	2.9	3.8	2.2	3.0
80	1.8	2.6	1.1	1.7
100	0.8	1.3	0.3	0.7
120	0.2	0.5	0.08	0.12

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SECTION 9

EFFECTS OF SOLVENT SIZING AND DESIZING ON THE ENVIRONMENT

One of our Nation's goals in its efforts to eliminate or change those practices which are detrimental to our environment is water pollution abatement. The effluent from textile aqueous wet processes contains pollutants which must be removed or changed to prevent stream pollution. The removal of sizing materials on woven fabrics in the finishing plant is a major contributor to the BOD characteristic of the plant's waste water effluent.

Reduction in water consumption and recovery of the sizing materials which can be realized by the use of solvent sizing and desizing systems would substantially reduce waste water pollution. This reduction in pollution can also be achieved by use of a recently developed polyvinyl alcohol size reclamation system. Several plants have installed this system which provides for the recovery and recycling of approximately 75% of the polyvinyl alcohol size and recycling of the water used in desizing to the desize washer. Obviously, recycling of the water in the desizing process reduces water and energy consumption. However, energy used in the reclamation units must be considered in the total energy consumption. Information on this system was obtained from publications by Union Carbide Corporation (1) and Easton County Dyeing Machine Company (2).

One of the concerns in considering the replacement of aqueous textile wet processing with solvent systems is that the loss of solvent might result in serious air pollution. Therefore, all aspects of the effects on the environment must be considered when a new process is being evaluated.

MILL SURVEY

In order to determine the present consumption of water and energy, process exhaust and cost of sizing (slashing) and desizing processes, information was requested from a number of textile plants. The information received from typical plants is shown in Tables 14 and 15. The averages for the appropriate categories were used as the data for the conventional aqueous systems in Tables 16, 18, and 19.

WATER CONSUMPTION AND WASTE WATER TREATMENT

Water is used in conventional aqueous sizing systems to make the size mix, washing the size applicator and washing the size mix and slasher areas. These operations do not require a great amount of water. These wash waters plus infrequent dumping of sizing materials are the only contribution from the slashing or sizing operation to the plant's water pollution and waste water treatment is not a major problem for weaving mills. Since the

[illegible]

[illegible]

[illegible]

| | | |

sizing material in the PVA reclamation system is applied in the normal manner, the water consumption and waste water effects should be the same in sizing as the conventional systems.

The principal investigators made several visits to manufacturers of solvent equipment and received information from them and others. As shown in Table 17, 3.4 gallons of water are consumed per pound of warp yarn. The majority of this is used by the condenser and is suitable for use as warm process water. It is reported that the waste water from the water solvent separator for the condensate from washing activated charcoal filters contains 0.015% by weight perchloroethylene and that this could be eliminated (3).

Information from typical plants showed an average of 0.98 gallons of water consumed per pound of fabric for the desizing process using conventional aqueous systems. In the PVA reclamation system (1-3) the permeate from the filtration system is reusable hot water which is returned to the desize washer. The actual water consumption is 0.54 gallons per pound of fabric and possibly less. In a solvent desizing machine the use of water is similar to that in the sizing machinery and the consumption is approximately the same. As shown in Table 17, 3.4 gallons of water are consumed per pound of fabric and most of this is used in the condenser. Since it is not polluted it is suitable for use as warm process water.

Table 16 shows the pollutional load contributed by desizing various sizing materials in aqueous systems. Warp yarns which have been sized with starch are responsible for a large part of the pollutants in the waste water effluent from a woven fabric finishing plant. The majority of the BOD$_5$ is due to the modified and converted sizing material which is removed from the fabric. In the PVA reclamation system 70% or more of the sizing material is reclaimed (1-3) (4). This will greatly reduce the waste water pollution from this desizing process. The effect of the solvent desizing system on the pollutants in the waste water effluent would be similar to that from the solvent sizing system.

EFFECTS ON AIR QUALITY

The majority of air exhausted from the slasher using conventional aqueous sizing systems is that taken from the hood over the drying cylinders. An additional general exhaust of the area is also normal for this operation. As shown in Table 17, 1,186 cubic feet of air are exhausted per pound of warp yarn. This air contains water vapor and small quantities of sizing materials and lint. The air exhausted from the slashers using the PVA reclamation system should be very similar to that from conventional systems.

In a solvent sizing or desizing system the majority of the solvent must be recovered in order for the process to be economically feasible and to prevent air pollution by solvent vapors which are exhausted from the system. Procedures which are being used to recover solvent from the new commercial sizing range and commercial desizing and scouring scopes are as follows:

A. Distillation--The solvent used to clean rolls in a sizing or desizing range and the soiled solvent is pumped to a storage

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TABLE 17. ENVIRONMENTAL EFFECTS OF AQUEOUS AND SOLVENT SIZING (SLASHING) SYSTEMS

UNIT/ENTITY	AQUEOUS SYSTEMS		SOLVENT SYSTEM
	Conventional	PVA Reclamation	
Gallons of water consumed per pound of warp yarn	0.25	0.25	3.4*
Effect on plant's total waste water	minor	minor	minor
Cubic feet of air exhausted per pound of warp yarn	1,386.0	1,386.0	44.2**
Pounds of perchloroethylene loss per pound of warp yarn	---	---	0.033
Concentration in ppm of perchloroethylene in atmosphere at:			
preheration machine	---	---	40.0
distillation unit	---	---	30.0
exhaust stack	---	---	100.0**

*Majority is recovered and available for process water.

**From carbon filters. Does not include other units.

tank for soiled solvent. This solvent is introduced into a still where it is heated by means of steam. The vapors are fed into a water-cooled condenser and the liquid is then passed through a water-separator. The water from the separator is passed to waste and the solvent goes to a clean solvent tank from which it is introduced again into the system. The residue in the still will contain the sizing material plus waxes, fats and oils which have been removed from the fibers. Machinery manufacturers have reported 90% size recovery which would require only 10% new material to be added to the system.

B. Condensation--Practically all of the solvent should be evaporated from the yarn or fabric in the drying chamber and a test probe and controller unit for monitoring the proportion of solvent in the drying chamber is available. The saturated air from the drying chamber passes through a water-cooled condenser and a portion of this air is recirculated in the dryer and the other goes to an activated carbon absorption unit. The solvent which is condensed in this unit goes to the clean solvent storage tank.

C. Absorption by activated carbon--The dried warp or fabric passes through a vacuum or deabsorbing section as it leaves the dryer. Some manufacturers also use a similar vacuum at the entrance slot to help maintain a slight negative pressure in the unit and to capture any solvent which might escape from this opening. The air from the vacuum section is passed through an activated carbon filter system. The carbon absorbs the solvent from the air and the clean air is then exhausted to the atmosphere. When the carbon bed nears its efficiency limit, the air is diverted to a second carbon unit for absorption. The first carbon bed then goes into the desorption portion of the cycle which consists of passing steam through the carbon bed in the direction opposite to that in which the solvent laden air had been flowing. The steam distillate goes through a water-cooled condenser and the condensate passes through a water separator. The water from the separator goes to waste and the solvent is pumped to the clean solvent storage tank. The absorption and desorption cycles of the carbon filter beds can be automatically controlled.

As shown in Table 17, 44.2 cubic feet of air per pound of warp yarn are exhausted from the carbon filters. Some have reported a concentration of 100-150 parts per million of solvent in this air, and the concentration may be higher toward the end of the cycle time of the carbon absorption unit. This concentration could be reduced with a more efficient carbon bed and more frequent transfer to the alternate beds.

Perchloroethylene is lost from the solvent system in the exhaust air from the carbon filters, general exhaust, water-solvent separators, residue from the still and residual solvent in the polyester fiber. The total loss should not exceed 0.033 pounds of perchloroethylene per pound of warp yarn.

No one has reported any problems in meeting the TLV for perchloroethylene in the working area around the ranges since most of these units are engineered to maintain a slight negative pressure in the units to prevent escape of solvent at the machine. A report on solvent scouring for knit goods (5) shows concentration of perchloroethylene in the atmosphere as shown in Table 17.

Table 18 shows the exhaust air from the carbon filters on a solvent desizing system as 29.4 cubic feet of air exhausted per pound of fabric and a total loss of 0.0525 pounds of perchloroethylene per pound of fabric. The concentration of perchloroethylene in the atmosphere should be similar to that on the solvent sizing system.

The combined environmental effects of various sizing and desizing systems are shown in Table 19. These totals are per pound of fabric for sizing and desizing and the warp yarns are considered to be 60% of the fabric weight.

TABLE 18. ENVIRONMENTAL EFFECTS OF MANUAL AND SOLVENT DRYCLEANING SYSTEMS

Category	Manual system		Solvent system
	Conventional	PVA Reclamation	
Gallons of water consumed per pound of fabric	0.98	0.04	3.4*
Effect on plant's waste water treatment	major	minor	minor
Cubic feet of air exhausted per pound of fabric	268.2	268.2	29.4**
Pounds of perchloroethylene loss per pound of fabric	---	---	0.0525
Concentration in ppm of perchloroethylene in atmosphere at:			
percholorination machine	---	---	40.0
distillation unit	---	---	30.0
exhaust stack	---	---	100.0**

*Majority is recovered and available for process water.

**From carbon filters. Does not include other units.

TABLE 19. SUMMARY* OF ENVIRONMENTAL EFFECTS OF AGARAN AND SOLVENT DYEING AND FINISHING SYSTEMS

CATEGORY	AGARAN SYSTEMS		SOLVENT SYSTEM
	Conventional	With Recirculation	
Gallons of water consumed per pound of fabric	1.13	0.69	5.44**
Effect on plant's waste water treatment	major	minor	minor
Cubic feet of air exhausted per pound of fabric	1,099.8	1,099.8	55.92***
Pounds of perchloroethylene loss per pound of fabric			0.0733

*Totals per pound of fabric for sizing and desizing. Warp yarns are considered as 60% of fabric weight.

**Majority is recovered and available for process water.

***From Cuatom filters. Does not include other units.

[illegible]

SECTION 10

ENERGY CONSUMPTION OF AQUEOUS AND SOLVENT SIZING AND DESIZING SYSTEMS

ENERGY CONSUMPTION OF SIZING SYSTEMS

Table 10 contains data on energy consumption of aqueous and solvent sizing systems as determined from mill surveys, technical literature and information provided by solvent processing machinery manufacturers. The majority of thermal energy consumed in a conventional aqueous system is in the form of steam which is used for the drying cylinders around which the warp yarn passes for removal of water. This can be minimized by use of a single-dip system and low wet pickup (4). Steam is also required for preparing the sizing materials and to maintain the correct temperature in the size applicator. The thermal energy in Tables 20,21 and 22 has been calculated as BTU's of fuel since the steam requirements have been adjusted for boiler efficiency and line losses. Electrical energy is consumed by the motors which are required by the process machinery (slasher) and exhaust fans for the hoods over the drying cylinders. Conventional equipment and procedures are used for applying the size on the PVA reclamation system. Therefore the energy consumption would be the same for both aqueous systems.

In the solvent sizing system thermal energy is required to heat the air in the hot air dryer and in the still for the solvent recovery system. Since less energy is required to evaporate perchloroethylene compared to water, the thermal energy consumption of the solvent system for sizing is approximately 40% that of the aqueous systems. Electrical energy is consumed by the motors on the process machinery including the circulating and exhaust fan in the dryer section and the pumps for the recovery units. The total consumption of energy for the solvent system is less than 50% of that for the aqueous systems.

ENERGY CONSUMPTION OF DESIZING SYSTEMS

Energy consumption of aqueous and solvent desizing systems is shown in Table 21. In removing conventional sizing materials from yarns thermal energy is required to heat the desizing solution, maintain the correct temperature of the fabric during the chemical reactions and to heat the water which is used to remove the materials from the fabric. Energy for drying the fabric is not included since in a continuous aqueous process the fabrics normally pass from desizing to a subsequent process without intermediate drying.

Detail information on the energy consumption of the PVA reclamation desizing system was not available to the investigators. According to reports and personal communications with machinery manufacturers, the total energy

consumption should be less than that for conventional systems due to reuse of water in the desize washer. The thermal energy consumption would be considerably less since the wash water is recycled to the desized washer but the electrical energy consumption would be much higher on account of the requirements of the PVA recovery system.

Drying of the fabrics is required in the solvent system so that the solvent may be recovered. Thermal energy is required for drying the fabric and for the solvent and sizing material recovery systems. These demands result in a high thermal energy consumption for the solvent system compared to aqueous systems. The electrical energy consumption includes the demands for the process machinery and the recovery systems.

The total energy consumption of a solvent desizing system is considerably higher than that for an aqueous system. This is due to the requirements for drying the fabric and recovering the materials in the solvent system.

TOTAL ENERGY CONSUMPTION OF SIZING AND DESIZING SYSTEMS

Table 22 contains a summary of energy consumption of aqueous and solvent sizing and desizing systems. The total energy consumptions were calculated based on the fabric containing 60% warp yarn by weight. The percentage of warp yarn will vary with different fabric styles but 60% is a reasonable average.

As compared to aqueous systems for sizing and desizing, the solvent system requires less energy for sizing but more for desizing. The total energy consumption for sizing and desizing with an aqueous system is approximately the same as the energy consumption for solvent systems. Therefore, there would be no appreciable energy savings for replacement of aqueous sizing and desizing systems with solvent systems.

TABLE 22. ENERGY CONSUMPTION OF AQUEOUS AND SOLVENT SIZING (DESIZING) SYSTEMS

CATEGORY	AQUEOUS SYSTEMS		SOLVENT SYSTEM
	PVA		
	Conventional	Recirculation	
Thermal BTU's consumed per pound of warp yarn	2082.3	1095.3	802.3
Electrical BTU's consumed per pound of warp yarn	87.7	87.7	193.0
TOTAL BTU's consumed per pound of warp yarn	2170.0	2170.0	995.3

TABLE 21. ENERGY CONSUMPTION OF AGARAN AND DURAPET DRYING SYSTEMS

CATEGORY	AGARAN SYSTEMS		DURAPET SYSTEM
	Conventional	PVA Reclamation	
Thermal BTU's consumed per pound of fabric	1361.5	*	1960.0
Electrical BTU's consumed per pound of fabric	50.1	*	149.0
TOTAL BTU's consumed per pound of fabric	1411.6		2109.0

*Exact information not available.

TABLE 22. SUMMARY* OF ENERGY CONSUMPTION OF AGARAN AND DURAPET DYEING (BLEACHING) AND DRYING SYSTEMS

CATEGORY	AGARAN SYSTEM Conventional	DURAPET SYSTEM
Thermal BTU's consumed per pound of fabric	3613.7	3441.4
Electrical BTU's consumed per pound of fabric	102.7	265.6
TOTAL BTU's consumed per pound of fabric	3715.4	3707.0

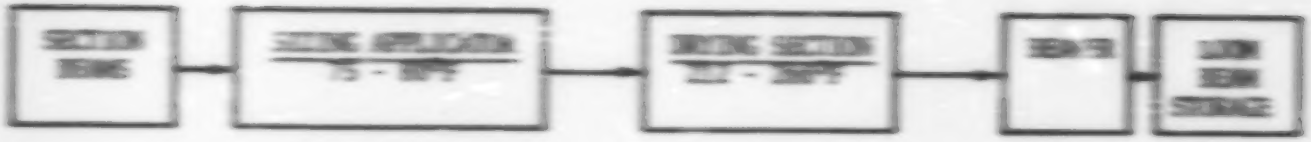
*Totals per pound of fabric for sizing and desizing. Warp yarns are considered as 60% of fabric weight.

[illegible] SIZING AND DESIZING FLOW DIAGRAMS

Figure 13 is a flow diagram of a solvent sizing system. The size is applied from perchloroethylene at 75-80°F. Drying occurs in air at between 212°F. and 266°F. The add-on of ethyl cellulose or hydroxypropyl cellulose to the yarn is about 9.0% and 4.3% perchloroethylene on weight of fabric is lost. This loss can probably be further reduced by improved machinery maintenance and additional carbon adsorption capacity.

Figure 14 is a flow diagram of a solvent desizing system. Size removal from the fabric would take place at 75-80°F. Drying of the fabric is in air at 212° to 266°F. All of the size is removed by the solvent and 95% of the size is recovered for recycle. Solvent loss is 5.25% of the weight of fabric processed. This loss can probably be reduced by improved machinery maintenance and additional carbon adsorption capability.

Figure 11. Solvent Sizing Flow Diagram

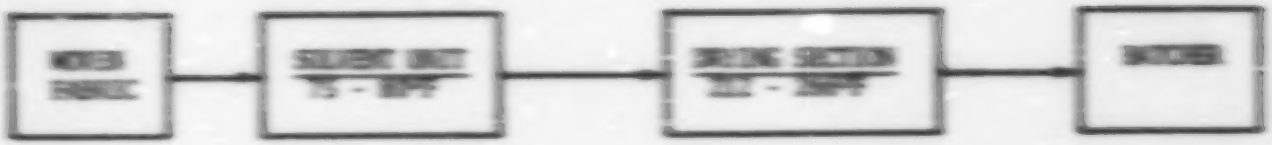


MATERIAL BALANCE

Item	In Fiber (lbs/100 lbs fabric)	Recovered (lbs/100 lbs fabric)	Lost Fiber (lbs/100 lbs fabric)
Sizing Material	5.0	—	5.0 (in yarn)
Perchloroethylene	140.0	137.7[a]	2.3[b]

[a] From condenser & dryer, distillation unit and carbon filters.
[b] 0.5 lbs in yarn. 1.8 lbs from filters, water separator and general exhaust.

Figure 14. Solvent Recycling Flow Diagram



MATERIAL BALANCE

Item	In Out (lbs/100 lbs fabric)	Recovered (lbs/100 lbs fabric)	Net Out (lbs/100 lbs fabric)
Sizing Materials	5.0[a]	4.50	0.50
Perchloroethylene	150.0	144.75[b]	5.25[c]

[a] Based on fabric containing 5% warp by weight.
[b] From condenser at dryer, distillation unit and carbon filters.
[c] 0.5 lbs in fabric. 4.75 lbs from filters, water separators and general exhaust.

SECTION II

ECONOMIC EVALUATION OF SOLVENT SIZING AND SIZING

Before any new process is adopted the economic impact of the process must be evaluated. The economic impact of replacing aqueous sizing systems with solvent systems depends on the comparative cost of materials, energy, machinery depreciation and waste water treatment. These are the costs which may substantially vary between these processes and there should be no significant differences in the other items of cost. Material costs for solvent systems will be greatly dependent on the recovery of sizing materials and loss of perchloroethylene. Improvement in efficiencies in these areas would have a great effect on the total cost of this system.

Reduction in material cost and waste water treatment are objectives of the recently developed PVA reclamation system. The majority of the sizing material is recovered and reused in the sizing (slashing) process. This greatly reduces not only the material cost but also the pollutants in the waste water from the finishing plant.

COST OF SIZING SYSTEMS

Table 33 contains cost of material, energy and machinery depreciation per pound of warp yarn for two aqueous systems and a solvent system of sizing. The material cost for the conventional aqueous system is higher than the other two due to the fact that starch, (PVA) or starch blended with other materials is removed from the fabric and is not recovered. A majority of the sizing material is recovered in the solvent system but the material cost is greatly affected by the loss of perchloroethylene. The material cost for the PVA reclamation system is the lowest of the three and a majority of the sizing material is recovered for approximately 1/6th the cost of new material. This cost also includes shipping the recovered PVA a moderate distance from the finishing plant to the weaving mill. The energy cost for the conventional and PVA reclamation aqueous systems should be the same but it is approximately twice that for the solvent system. This is primarily due to the large energy requirements for removing perchloroethylene compared to water. The machinery depreciation cost for the solvent system is approximately 50% greater than that for the aqueous systems. The total cost of the items evaluated of the conventional aqueous system is slightly higher than that of the solvent system. The cost for the PVA reclamation aqueous system is considerably less than for the other two.

TABLE 24. COSTS OF AQUEOUS AND SOLVENT DESIZING (DEACTIVATION) SYSTEMS

CATEGORY	AQUEOUS SYSTEMS		SOLVENT SYSTEM
		PVA	
	Conventional	Reclamation	
Cost of material per pound of warp yarn	$ 0.0394	$ 0.0220	$ 0.0361
Cost of energy per pound of warp yarn	0.0059	0.0059	0.0031
Cost of machinery depreciation per pound of warp yarn	0.0014	0.0014	0.0020
TOTAL	$ 0.0467	$ 0.0293	$ 0.0412

COST OF DESIZING SYSTEMS

Cost of material, energy, machinery depreciation and waste water treatment are shown in Table 24. Exact information on energy consumption of the PVA reclamation aqueous system was not available and therefore this system will not be considered in evaluating desizing systems. Contribution of the perchloroethylene which is lost in the solvent system to the cost of material for this system results in the material cost being much higher than that for conventional aqueous systems. The energy cost for the solvent desizing system is also much higher than that for the conventional aqueous system since only the solvent system requires drying of the fabric. The machinery used in the solvent desizing system is much more expensive than that used for the aqueous systems and therefore the machinery depreciation cost is higher. The cost of waste water treatment varies widely from the 1977 to the 1983 requirements. Only a very small quantity of the waste water from the solvent system is introduced into the plant effluent and therefore the cost of treatment relating to this process is small.

The comparative cost of aqueous and solvent desizing depends greatly on cost of waste water treatment. Using the figure $0.0014 for BPT treatment in 1977, the aqueous system has a decided cost advantage over the solvent system. When the figure $0.0066 for BAT treatment in 1983 is used, the aqueous system has a small cost advantage. Although information on desizing cost with the PVA reclamation system was not complete, the cost of reclaimed PVA was available to the investigator by means of personal communication from a machinery manufacturer.

TABLE 24. COSTS OF AGARAN AND SEAWEED [illegible] SYSTEMS

CATEGORY	AGARAN SYSTEMS		SEAWEED SYSTEM
	Conventional	PVA Reclamation	
Cost of material per pound Fabric	$ 0.0041	$ 0.0006	$ 0.0103
Cost of energy per pound of Fabric	0.0033	*	0.0052
Cost of machinery depreciation per pound of Fabric	0.0033	0.0025	0.0014
Cost of waste water treatment per pound of Fabric**			
(BPT-1977)	0.0014	*	0.0001
(BAT-1983)	0.0066	*	0.0007
TOTAL (BPT-1977)	$ 0.0091	---	$ 0.0170
(BAT-1983)	$ 0.0143	---	$ 0.0176

*Information not available

**Waste water from mixing and desizing processes.

TOTAL COST OF SIZING AND DESIZING SYSTEMS

The total cost of aqueous and solvent sizing and desizing systems has been calculated and is shown in Table 25. The total cost per pound of fabric was calculated with warp yarns being considered as 60% of fabric weight. The total cost for the conventional aqueous system shows a slight advantage over the solvent system based on water treatment cost for 1977. The cost for the two systems is practically the same when water treatment costs for 1983 are included.

TABLE 25. SUMMARY[a] OF COSTS OF AQUEOUS AND SOLVENT SIZING (SLASHING) AND DESIZING SYSTEMS

CATEGORY	AQUEOUS SYSTEMS Conventional	SOLVENT SYSTEMS
Cost of material per pound of fabric	$ 0.0277	$ 0.0380
Cost of energy per pound of fabric	0.0060	0.0071
Cost of machinery depreciation per pound of fabric	0.0011	0.0030
Cost of waste water treatment per pound of fabric[b]		
(BPT-1977)	0.0014	0.0001
(BAT-1983)	0.0066	0.0007
TOTAL: (BPT-1977)	$ 0.0370	$ 0.0610
(BAT-1983)	$ 0.0422	$ 0.0624

[a]Totals per pound of fabric for sizing and desizing warp yarns are considered as 60% of fabric weight.

[b]Waste water from sizing and desizing processes.

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APPENDIX A

ENGLISH TO METRIC CONVERSION FACTORS

1 inch (in) = 2.540 centimeters (cm)

1 foot (ft) = 30.48 cm

1 yard (yd) = 0.914 meters (m) = 91.44 cm

1 cm = 0.394 in

1 pound (lb) = 0.454 kilograms (Kg) = 453.6 grams (g)

1 Kg = 2.205 lb

1 gallon (gal) = 3.785 liters (l)

1 l = 0.264 gal

$^{o}F = 9/5\ (^{o}C) + 32$

$^{o}C = 5/9\ (^{o}F - 32)$

APPENDIX B

GLOSSARY

Certain terms used in this report have special meanings in the field of textiles. These definitions are provided here to assist readers who do not have a textile background.

Break factor - the numerical product of the breaking strength in ounces of a yarn and the yarn's cotton count.

Bust, lease or split rod - stainless steel rods used in a slasher to split or separate the yarns which have been stuck together with sizing material.

Cam draft or Order of lifting - technical draft illustrating the order by which the harnesses of a loom are raised and lowered during the weft insertions of the weave pattern.

Cotton Count - A number expressing a yarn's length per unit weight where the number represents the "count" of 840-yard lengths that weigh exactly one pound.

Creel - that section of a textile process or machine where stock is placed for feeding into the process or machine.

Dent - in a loom reed, the space between two reed wires usually expressed as "dents per inch" meaning spaces available in one inch of reed. Also known as the reed number.

Draw draft or Order of entering - technical draft illustrating the order by which the warp yarns are drawn into the heddles of the loom harnesses or which yarns of the weave pattern are controlled by each harness frame.

End - a single yarn, usually in the warp.

Expansion comb - a device used at the slasher to properly space the yarns prior to winding of the yarn sheet onto the loom beam.

Filling - the widthwise yarns in a woven fabric also weft yarns.

Harnesses - frames that contain the heddles for control of warp yarns in a loom.

Motes - small pieces of seed or vegetable matter which were not removed from cotton in ginning or subsequent processes.

Pick - a single filling or weft yarn in a woven fabric.

Reed - the part of a loom that dictates the [illegible] of warp ends to determine ends per inch in the fabric.

Splitting - separation of sized warp yarns by action of the heat or leasse rods.

Warp - the lengthwise yarns in a woven fabric.

Weave draft or Order of interlacing - technical draft illustrating the order by which warp yarns are interlaced with the weft or filling yarns of the weave pattern.